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ENGINEERING

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A MYTH

ONE of the incidental commitments of being an engineer is that relatives, friends and acquaintances expect us to be able to explain anything mechanical or electrical which is currently receiving popular attention. With so much happening in the engineering world this innocent faith in our omniscience is rather flattering. It is so hard to live up to that often the easiest way out is to make a virtue of ignorance, by stressing the degree to which engineers specialise. But that is a disservice to the profession, tending to widen not only the gulf between engineers and laymen, but also the gulf between specialist engineers.

There are always, however, certain engineering topics of general interest on which engineers can, and should, have decided views. One of great significance to-day is automation. All kinds of wild statements are being made about the future effects of automation on society and industry, so it is urgently necessary for engineers to help in fostering a sense of proportion about the prospects. Older engineers may be tempted to be cynical: to off-set the fashionable optimism by quietly pointing out that it is, after all has been said, only an extension of developments which have been growing since the Industrial Revolution. But that response, too, would be a disservice to engineering, encouraging cynicism among laymen who are not able to reach a reasoned conclusion themselves.

Through the mass media of the Press, broadcasting and television, people are being encouraged to believe that automation will permit so much work to be done by machines that there will be unemployment or a shorter working week, or both. Twenty years of full employment have dimmed the spectre of unemployment, so that there is now not the public outcry against automation that there would have been if anyone had dared to preach it in the early 1930's. Indeed, the trades unions have, on the whole, taken a reasonable and optimistic view of the benefits that automation can bestow if the changes are controlled with a sense of social responsibility. It is rightly believed that certain over-riding factors, such as the limited supply of technologists and technicians, will act as an automatic damping influence, steadying the rate of change and preventing any sudden effect which might result in unemployment.

With automation found "not guilty" of causing unemployment, the pendulum swings the other way and the talk is of a shorter working week. The necessities and luxuries of life will flow from factories that are planned by a few technologists and maintained in production by a few technicians. Everyone will have more leisure and the standard of living will continue to rise. That is a picture of the future which should be exposed as a myth—a popular fantasy which may have propagandist and political appeal but is most unlikely to materialise.

Compared with his ancestor of the Middle Ages, an Englishman is served by the equivalent of 13 or 14 slaves, and an American has 27 slaves. These figures were given by Dr. A. Parker in his Thomas Hawksley Lecture of 1949. He arrived at them by aggregating the power consumption of each nation and dividing it by the population. If allowance is made for the increase in productivity during the past six years, and if a further allowance is made for the increase in industrial efficiency during the past few centuries (an increase which can be conveniently covered by a steady extension in the principle of the division of labour), then civilised man in 1955 must have a very large number indeed of invisible slaves. If a great scientist of the past—Newton, say—could visit us to-day, and we were to tell him about these wonderful slaves, he would certainly congratulate us on the widespread leisure that we must surely enjoy, and he would no doubt express a hope that we were making good use of it. But we would have to admit that many people still have to work long hours. We could explain this situation partly by saying that our standard of living is high, but we would also have to admit that many of the slaves are devoted to the production of weapons and to other activities that are of no direct benefit to men and women.

The truth is, of course, that every increase in the ability to produce is sooner or later absorbed by an increase in the ability to consume. In so far as there has been a progressive reduction in the working week, it has been rendered possible by science and engineering, but it has been brought about by the pressure of organised labour. Without that pressure the working week would not be as short as it is to-day. Even now the *Daily Express* has made a statesmanlike appeal to everyone to work half an hour extra every day, in order to overcome the nation's financial difficulties. Far from working fewer hours, the need is to work more hours. All pseudo-welfare ideas apart, a marked increase in leisure is not to be desired. Saints alone would know how to use it. The ordinary man is happiest when he knows he is expected to work—for himself, his family and the community. And if ever he is tempted to have a week-end that is longer than the working week, it would be better for him to look over the seas to other lands where every man is still his own slave.

Weekly Survey

Cover Picture. *Early steamships had tall funnels to ensure the proper combustion of the boiler fuel, and the tall funnels had the additional advantage of being the means of carrying away smoke clear of all parts of the ship. With improved methods of combustion a shorter funnel is often used in modern ships, but it creates problems of smoke dispersion. The cover picture shows a novel type of ship's funnel being tested in a wind tunnel. These tests show how successful new designs are in carrying the smoke clear of the ship.*

* * *

POWELL DUFFRYN ON COAL

A timely comment on the consequences of this country's imminent withdrawal from the coal export market comes in the chairman's statement accompanying the latest annual accounts of Powell Duffryn Limited. Says Sir Herbert Merrett: "The most significant features of the coal position in this country are firstly the increased consumption and demand for coal and, secondly, the failure of the industry to produce it. Although coal bunkering at home and abroad has fallen to a mere fraction of pre-war figures there remains at the moment a considerable demand for British coal from overseas countries and old established markets, which we are unfortunately unable to meet." At a time when a sigh of relief is going up that plentiful nuclear energy will fill the gap between potential demand and supply which dear and scarce coal cannot fill, the consequencies for this country of its becoming a net importer of solid fuel should be borne in mind. The implications of this change on this country's international trade, its shipping and bunkering activities have still to be fully worked out.

Meanwhile Powell Duffryn's policy of developing its coal distributive activities and of moving gradually into the engineering field has been further vindicated this year. The Stephenson Clarke group of companies have continued to play an important part in coal distribution in this country (both rail-borne and sea-borne). The 30 coastal colliers have been partly employed in importing coal from the Continent and further capital expenditure on this side of the group's activities has been put in hand, five new ships on order being expected to start trading in the next year or two. The company's bunkering interests in this country and abroad have had a satisfactory year and Powell Duffryn have now acquired the agency for Ford cars and lorries in Aden. The timber interests owned through Cory Brothers & Company, Limited, have also done well. Directly or through its subsidiaries, the parent company now has an interest in the engineering field which includes heating systems, oil tanks, steel wagons and heat exchangers, and in addition there are the technical services which are organised in a separate subsidiary company that is now operating over a wide field which includes Korea. Powell Duffryn continues to be an outstanding example of the application of finance accumulated originally in a basic extracting industry and applied with energy and acumen in a wide range of industrial activities, merchanting and technical services.

* * *

THE TWENTIETH SHOW

Every second year since 1906, with the exception of the war years, the Engineering, Marine and Welding Exhibition has been held at Olympia. Every fourth year, as this year, there is joined to it the Foundry Trades Exhibition, while in 1953 there was incorporated the Chemical Plant Exhibition. In either combination, the display can probably be counted to give the best all-round picture of the most recent developments in engineering and of the range of equipment available.

This year, at the inaugural luncheon, the main speaker was His Excellency the Hon. Sir Thomas White, K.B.E., D.F.C., High Commissioner for Australia. Sir Thomas, in wishing success to the exhibition, remarked on the enormous range and output of high quality goods from what was in reality a very small island. He urged that the important aim for the future was the upkeep of quality to follow the great traditions of the past, and to guarantee a market in the future. The links of prosperity were closely bound with international, and particularly inter-Commonwealth, trade, which itself was governed by the purchasing power of the countries concerned. And, he continued, purchasing power was dependent on export credits. There was much room for expansion in Australian production and additional labour was needed for this. He closed with a repeated appeal for greater trade within the Commonwealth.

In an introductory speech, the chairman of the exhibition, Mr. H. S. Broom, M.B.E., B.Sc., M.I.Mech.E., recalled the growth of the exhibition and in particular the development during the last two years. In 1906 there had been 100 exhibitors, now it was over 500. The developments of atomic power and the rapid advance of automation were plainly to be seen in industry; in both, electronic controls were playing an enormous part. He expressed the thanks of all concerned to the firm of F. W. Bridges and Sons, Limited, who had organised the exhibitions since the first in 1906.

* * *

SEASONAL PAUSE

The holiday season always brings a deceleration in this country's rate of economic activity. Industrial activity slackens off and the seasonal pressure on sterling increases as the bill for the summers's large purchases of foodstuffs is gradually paid off. Tnis year, the drop in impetus nas been particularly marked. According to the official index of industrial production, the index for all industries in June was 136, compared with 138 in May and 128 in June, 1954. At the end of the half year, therefore, industrial output was running 8 points ahead of the corresponding period last year, but there was a drop of 2 points between May and June. Since June is a shorter month than May and there were the dock and railway strikes to take into account, the June figure was fairly satisfactory. According to provisional estimates for July, the index is likely to have been 121 or 122 compared with 117 in July, 1954. This is a drop of 14 or 15 points on June and may be compared with a drop of 11 points between June and July, 1954. The decline in industrial activity therefore in July was probably somewhat severe.

Now that the August figures are available for the gold and dollar reserves it is apparent that pressure in that direction has also been serious. The reserves fell by 87 million dols. to 2,457 million dols. This was slightly less than the fall in August, 1954, but even after the drop in August last year the reserves stood at 2,918 million dols. and had not been called upon to absorb a severe drop in the previous month. Some of the fall in August has been due to heavy tourist disbursements but some of it has certainly been caused by speculation on the Continent in anticipation, however strenuously denied in this country, of a devaluation of sterling. Opinion abroad continues to be much less optimistic than opinion at home that this country's economic house is in good order.

Data continue to accumulate of the competitive strength of other countries, notably Germany. Figures put out recently by the British Engineers' Association show that the value of British exports of electrical and mechanical engineering products remained remarkably stable between 1952 and 1954 (they actually rose by £8 million to £578 million in 1953 but returned to the 1952 level in 1954) while exports of similar goods from the United States fell somewhat last year. In contrast, West German exports rose by 14 per cent. last year to £506 million. Most of this engineering equipment went to Europe but important gains were made in India and Latin America. German exports to India have actually doubled since 1952 and isolated examples so far this year suggest that the edge of German competition in that sub-Continent has by no means been blunted. There was another disturbing comment last week, this time from the managing director of Shell Tankers, about the attractive terms of contract available at some Continental shipbuilding yards. It is vital that at a time when the engineering industry is being called upon to make an increasing effort in export markets it should not be bedevilled by inordinate pressure from the side of wages to increase costs and prices.

* * *

FLEXIBLE STAINLESS-STEEL TUBES

Of particular interest to the aircraft industry is the announcement by Accles and Pollock, Limited (a member of the Tube Investment group) that they are going to manufacture flexible seamless stainless-steel tube. A short article on the tube appears in this issue. After months of development work and discussions with the aircraft industry about the range of sizes to make economic production possible at the earliest moment, a limited range of bores and gauges of tube has been established.

A good deal of work has been done recently on tubing, following the tendency for pressures to increase in hydraulic systems and the growing heat and vibration problem in gas-turbine engines. An added attraction of stainless-steel in hydraulic lines is that it is immune from the corrosive properties of glycol-ether-water mixtures. Up to the present, hydraulic operation of undercarriages and flaps is still generally preferred by aircraft designers to electrical systems on the score of weight.

With temperatures already high, and tending to rise in the case of gas-turbine engines, there would seem to be good prospects for flexible steel tubing. It may also be that the accessory side of the aircraft industry will offer openings. There is competition in the field for supplying small-diameter flexible tubing to the hydraulic and engine side of the aircraft industry from plastics and other steel alloys, but the challenge of stainless-steel tubing is definitely increased now that flexibility has removed the coupling problem which existed so long as the tube remained rigid.

* * *

HIGH AUTHORITY LOANS

During the first six months of this year the High Authority advanced the 100 million dols., borrowed from the United States Export-Import Bank in April, 1954, to concerns within its six member countries. Some 31 million dols. have gone in colliery installations, 3·7 million dols. into coke ovens, 46·5 million dols. into thermal power stations and 18·8 million dols. into iron ore. Geographically the largest amount has gone into the Ruhr, but South Belgium, Lorraine and the Saar have also had more than 10 million dols. each. The money has gone to concerns which propose lowering costs of production in modernising collieries or iron ore mines, or which intend building or improving thermal power stations. This policy follows on the decision announced in January, 1954, by the High Authority to reduce costs so far as possible in the raw materials extracting industries. It will be noted that no allocation has been made to the steel industry as such. It had been intended to spend 25 million dols. on workers' houses but this has been held up by what the High Authority calls "technical financial difficulties," and the money for this purpose is being raised in Europe.

This 100 million dols. has helped to generate further capital investment. The High Authority

has ruled that it will loan only a portion of the funds required for any project and the initial 100 million dols. has gone into a total investment of 365 million dols. undertaken by 54 separate concerns. In May of this year the Investment Commission made a report to the Assembly which contained the following remarks: "In the Ruhr coalfield an average saving of slightly more than 0·25 dol. a ton is expected from investments affecting 33 million tons. In the coalfields of the Nord and Pas-de-Calais in France, the concentration of production will result in a saving of 1 dol. a ton on nearly 900,000 tons a year; the extension of a shaft will lead to an economy of 1·30 dols. a ton on 600,000 tons a year . . . Savings will result also from the modernisation and expansion of thermal power stations . . . In the Saar, the better use of low-grade products expected in one power station will lead to an increase of 0·25 dol. a ton in the market value of the whole output of the Saar mines (16,000,000 tons a year)."

* * *

SCARCE AMERICAN SCRAP

There have been signs recently that the U.S. scrap merchants are finding difficulty in meeting the demands of the home and export markets. In a recent eight-week period ending with the middle of August the price of scrap went up by 10 dols. to 44 dols. per ton. Steel production in the United States has been running at a record level recently and this has been accompanied by a scarcity of pig iron from the blast furnaces which has been caused partly by the recent short-lived steel strike and also by a large amount of maintenance work on blast furnaces. While these factors have been raising the demand for scrap in the domestic market, the continued boom in the world steel industry has raised exports of scrap to a new level. In the first half of this year 2·6 million tons have been exported compared with 1·7 million for the whole of 1954 and 304,000 tons for the whole of 1953.

During the first half of this year Britain imported 50 per cent. more scrap than in the corresponding period of 1954. Nevertheless, stocks at steel works and steel foundries represented less than three weeks' supply and they have been running down steadily since July, 1954. The position is in fact worse than it was two years ago. At that time there was also rather less than three weeks' supply of scrap in stock, but the steel industry was running at an average weekly output of 338,000 tons of steel ingots and castings compared with 364,000 tons in June of this year.

Last month, scrap users in the United States asked the Administration for some kind of restriction on exports, a move which was naturally opposed by export scrap dealers. The efforts of some sections of the American steel industry to bring official pressure to bear on the movement of scrap between the domestic and export market was not successful, but there are indications that the steel industry in this country is vulnerable enough to a reduction in its scrap supplies to watch the situation in America with care.

* * *

CHIEF JOSEPH AGAIN

The decision announced last week by the United States Administration that the bid by the English Electric Company for equipment in connection with the Chief Joseph dam project was unacceptable, was received with dismay by all countries who are trying to persuade their manufacturers to develop the American market. The persistent efforts of certain elements in the U.S. Administration to persuade powerful supply departments along the road of freer trade has met with remarkably little success, and the result is that those interested in developing trade between this country and America—on both sides of the Atlantic—are being forced to take up somewhat illogical positions.

On the British side it is clearly worse than being unable to submit a tender at all if tenders are nominally acceptable but in practice rejected for reasons of trade protection. Most British manufacturers would rather face an insurmountable tariff or a law forbidding foreign contracts than go through the expensive motions of competing only to be rejected as a matter of course. On the American side some of the more free-trade elements in the Administration are also coming round to the view that it would be better to discourage foreign tenders from the start rather than impair the foreign relations of the United States every time a competitive major foreign contract is ignored. There seem to have been efforts in Washington last week to justify a prohibition of foreign tendering for Government contracts by arguing that the amount of business which can be secured by foreign manufacturers from Government work is small, and that in any case larger orders are going to foreign manufacturers through the off-shore purchase system by which essential defence equipment is bought for the North Atlantic Treaty Organisation Powers with American dollars. While it would be churlish to under-estimate the size of the gesture made by the United States so far as off-shore purchases are concerned, the argument is quite unacceptable. The issue is one of free trade and it cannot be baulked. This fact should be acknowledged before either side succumbs to exasperation and stops the trend, admittedly at times almost imperceptible, towards a liberalisation of trade across the Atlantic.

* * *

WHITE ELEPHANTS OR GUINEA PIGS?

Some remarks made by Sir Robert Robinson, President of the British Association, while addressing the Bristol Rotary Club last Monday, raises a question which has privately troubled many: have we been too hasty in our atomic power plans? Britain has been compelled by the apparent exigencies of the fuel situation, the shortage and high cost of coal and oil, to take almost precipitate steps in the development of nuclear power, and a public review of the power programme in the light of current economic conditions and the information revealed at Geneva has now become due.

Sir Robert said that the multiplication of nuclear power stations at present was premature and remarked that there was a tendency to "write-off" coal and oil too soon.

The demand for an alternative to conventional fuels has made necessary the building of a comparatively large nuclear power station at an early date. The 50-MW plant at Calder Hall is expected, with returns from sale of plutonium, to produce electricity at a cost of 0·6*d.* per unit at the station busbars as against 0·72*d.* per unit for coal-fired plants in this country.

However, more advanced nuclear power stations—employing breeder, homogeneous, or even fusion reactors—may permit a much larger reduction in the cost of electric power. What is more, the value of plutonium, with increasing production and the prospect of a relaxation in the cold war, is likely to fall considerably. It is also noteworthy that the five reactor systems considered by the Americans to be economically most promising (ENGINEERING, page 282, August 26, 1955), do not include a gas-cooled graphite-moderated reactor such as that at Calder Hall.

The United Kingdom has, of course, other plans in view—a fast breeder reactor is to be built at Dounreay for example—and no doubt the authorities responsible have already considered the factors outlined above. American conclusions do not necessarily apply to British conditions, and it is certain that Calder Hall will provide an abundance of valuable experience.

Yet we must be careful that we do not, as sometimes in the past, allow this experience to yield greater profits overseas than at home—other countries with abundant coal stocks can afford to wait and adopt our hard-won answers to nuclear problems ready made. Calder Hall is a useful guinea pig, but we must not lag behind in exploiting the knowledge it provides.

It is necessary therefore to ensure that our initial lead does not place us behind later, that our first atomic power stations do not fall obsolete before they have yielded their cost in power output, that our guinea pigs do not become white elephants.

It is thus not only important for Britain to keep abreast of nuclear research but also for industry to equip itself with the necessary techniques for putting the results of research into practice. We must be prepared for the obsolescence of early stations and be ready with their replacements, and also make sure that our programme is in accordance with our means.

* * *

CLYDE BUILT

The fourth dual-purpose motor vessel on the Clyde is to be built by the Ailsa Shipbuilding Company, Limited, for British Railways, for service in 1957. This was announced last week as a further instalment of the £2 million modernisation programme for the Clyde steamer fleet. This news comes at the end of another successful year for the Clyde fleet and emphasises that the Firth of Clyde steamer services may have a prosperous future under efficient centralised management with a progressive technical policy.

Considerable interest, both nostalgic and technical, attaches to this Clyde fleet. It was born with the Comet in 1812, and the launching of the King Edward in 1901 saw the first application of the steam turbine to shipping on a commercial basis. This last was only a high-light in the growth of the Clyde steamers which for almost a century were the proving ground for the rapidly developing Clyde marine engineering industry. The halcyon days however were reached before the first World War. Since then, the gradual concentration of ownership of the fleet on the railways and then on British Railways, changing social habits and less willingness to build modern tonnage (oil-fuel burning and Diesel-electric ships have come slowly to the Clyde) saw the gradual if slow contraction of the steamer services and the size of the fleet. In the last few years, however, the decision to build dual-purpose ships to carry vehicles as well as passengers at reasonable rates from east to west of the Firth and back, the building of small Diesel-electric ships with low running costs in addition to these dual-purpose vessels, and the concentration of the turbine ships on the longer runs and excursion work has begun to show results. This fleet may never again be as large as it was 50 years ago but it shows signs of continuing to play a significant economic and technical role in Scottish shipbuilding.

* * *

COMBINED ELECTRICITY AND STEAM SUPPLY

There have been many suggestions in the past that the Central Electricity Authority should make greater use of the possibilities for economy which arise from the simultaneous supply of steam and electricity from a power station. Although many of the schemes put forward for this purpose have proved uneconomic there are others where the contrary is the case. Among these is one where it has been arranged that a substantial part of the steam used in the works of British Celanese, Limited, at Spondon, near Derby, shall be supplied from the adjacent power station of the Authority.

Conditions for the arrangement are favourable since the works and power stations are on adjacent sites; it will be possible for the company to dispense with some low-pressure boiler capacity; and it will bring about a saving of some 100,000 tons of coal per annum. Although the steam will be used at the relatively low pressure of 160 lb. per square inch it will be generated at 900 lb. per square inch and then reduced in special back-pressure turbines so producing electricity at a high thermal efficiency.

DIRECT-DRIVE GAS-TURBINE UNIT FOR TANKER

NEW POWER PLANT FOR THE AURIS

A model of a 5,500-h.p. gas-turbine unit, which is shortly to replace the existing composite propulsion plant aboard the 12,250-ton (d.w.) Shell Petroleum Company tanker Auris, is among the exhibits being shown by the British Thomson-Houston Company at the Engineering, Marine and Welding Exhibition. The model appears in the illustration below. This unit, which will serve in place of the 1,200-h.p. gas turbine and three Diesel alternators previously fitted (see ENGINEERING, vol. 171, page 209, 1951), will operate through a direct-drive transmission system and will incorporate double reduction gearing, with hydraulic means for reversing the rotation of the propeller shaft. It will also provide power for auxiliary purposes both at sea and in port and for discharging the vessel's petroleum cargoes.

In 1951, the Auris, which, as a test bed, has been the source of valuable experience, became the first merchant ship to be powered by a gas turbine. Since then she has completed 15,000 hours of active service. Although it is still early to foresee the application of the gas turbine to marine propulsion on a broad basis, the Shell Company have sufficient confidence in this prime mover to replace the four smaller power plants in the Auris with the single large gas-turbine unit.

The turbine will be of open-cycle design with intercooler and heat exchanger, and will operate as follows: intake air will pass through a low-pressure compressor, the intercooler, a high-pressure compressor and the heat exchanger to the combustion chamber where it will be heated by burning petroleum fuel. The combustion products will expand first through a high-pressure turbine, which drives the high-pressure compressor only, and then through a low-pressure turbine, which, in addition to driving the low-pressure compressor, produces the propulsive power. From the low-pressure turbine the products of combustion flow through the heat exchanger, thence to an exhaust-gas boiler, and finally to atmosphere.

5,500 B.H.P. TURBINE OUTPUT

The turbine is designed on the basis of an ambient temperature of 75 deg. F. and the turbine inlet temperature will be 1,200 deg. F. The expected output is 5,500 b.h.p., while the heat rate will be 9,100 B.Th.U.s per b.h.p. per hour; these figures neglect the waste-heat boiler output. It is proposed that the steam pressure in the waste-heat boiler will be 50 lb. per square inch gauge, and its evaporation rate 5,000 lb. per hour. The design speed of the high-pressure turbine shaft is 5,800 r.p.m.; the high-pressure compressor will have 16 stages and the turbine 5. The number of stages in the low-pressure compressor will be 12 and in the low-pressure turbine 8, and the shaft will be designed to revolve at 3,840 r.p.m.

Power will be transmitted through articulated double reduction gearing in conjunction with a hydraulic manoeuvring system of Pametrada design. A small-tooth flexible coupling will connect the low-pressure turbine with a quill shaft upon which will be keyed the driving wheels of the ahead hydraulic coupling and the astern torque coverter, arranged at the aft and forward ends of the first reduction pinion. The ahead coupling will consist of a driving and driven wheel; the astern converter will have in addition a fixed blade cascade between the two wheels. The driven wheels will be connected to the ends of the first reduction pinion.

MANOEUVRING

Manoeuvring will be effected by filling one or other of the couplings with oil, and will be controlled by means of a single-piston oil valve which will supply oil to the couplings as required. This valve will be interlocked with the fuel supply to the combustion chamber to prevent mishandling.

The ahead coupling is expected to have an efficiency of approximately 98 per cent. A direct-drive friction clutch in the same casing will be provided to eliminate the 2 per cent. loss when the transmission system is operating at full power in the ahead direction.

Auxiliary power will be supplied by a B.T.H. 200-kW steam turbo-alternator set, which will take steam from the waste-gas boiler when the Auris is at sea and provide electrical current for the ship's services. As a stand-by a 120-kW gas-turbine driven alternator made by W. H. Allen, Sons and Company, Limited, Bedford, will be fitted.

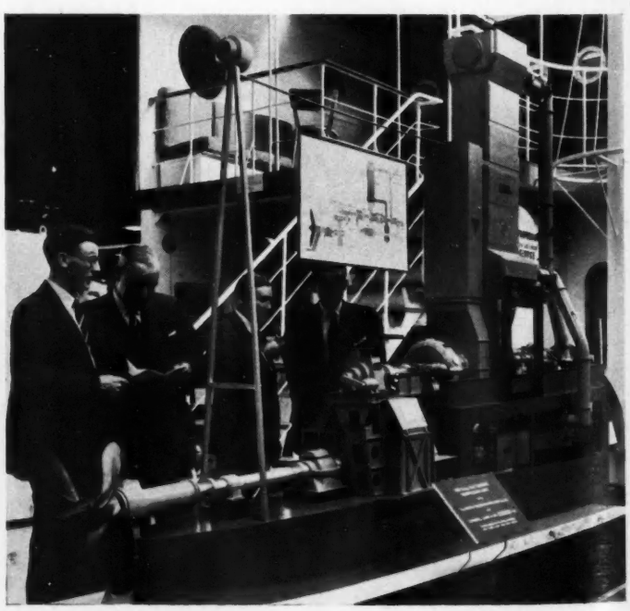
CARGO PUMPING

For cargo-pumping operations either at sea or in port, arrangements will be made for a B.T.H. 550-kW alternator to be readily connected to the main gearbox through a third fluid coupling situated aft of the ahead coupling. Its driving wheel will also be keyed to the quill shaft, and the driven wheel will be connected to a pinion of an additional reduction gear driving the alternator.

A 450-s.h.p. steam turbine will be installed as a reserve propulsion unit and a separate reduction gear will be provided so that it can be connected to the propeller shaft. This reduction gear will consist of a demountable pinion which will mesh with the first reduction wheel. Steam for the turbine would be supplied by an existing oil-fired boiler. Except for the stand-by gas-turbine alternator, normal commercial grades of boiler fuel will be used throughout.

The design and lay-out of the new installation for the Auris is the work of the British Thomson-Houston Company, Limited, Rugby, and Cammell Laird and Company, Limited, Birkenhead, acting in collaboration with the marine research and development department of the Shell Petroleum Company, Limited, Shell-Mex House, Strand, London, W.C.2.

Reference has also been made to the Auris and her propulsion plant in ENGINEERING on the following occasions: vol. 171, pages 209 and 322, vol. 172, page 307 (1951), vol. 173, pages 119 and 397, vol. 174, page 639 (1952), vol. 177, page 720 (1954), and vol. 179, page 66 (1955), when mention was made of the proposed replacement.



Model of the B.T.H. 5,500-h.p. gas-turbine propulsion unit which is shortly to replace the 1,200-h.p. gas turbine and three Diesel alternators previously installed in the Shell tanker Auris.

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40-SEAT HELICOPTER PROPOSED

Powered by Gas Turbines

The design and development of a new British transport helicopter, to be called the "Westminster," has been initiated by Westland Aircraft Limited, Yeovil, Somerset. Designed to meet a variety of military roles, the Westminster will be powered by twin gas-turbine engines and will be capable of carrying 40 passengers or 32 stretcher cases.

The configuration, of a single main rotor driven by twin engines mounted on the cabin top, has been evolved by the designers to take full advantage of the compact nature of British rear-drive gas turbines and to give maximum hovering performance. Because the builders have access to Sikorsky developments, full use will be made of mechanical systems and design features already successfully proved. This will mean a considerable reduction in the time required for development trials, and thus earlier production.

The Westminster will have a maximum all-up weight of 33,000 lb., of which 13,000 lb. will be available as disposable load. At this gross weight the range with full fuel load will be 310 nautical miles at a cruising speed of 130 knots.

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NEW BORG-WARNER FACTORY

Manufacture of Car Overdrives

The cornerstone of a new factory for Borg-Warner, Limited, was laid at Letchworth, Hertfordshire, on Wednesday, August 24, by Mr. R. S. Ingersoll, vice-President of the parent concern, the Borg-Warner Corporation. The new buildings, which are in an advanced stage of construction and the first of which will be opened within the next few weeks, cover an area of 12 acres and will, when completed, be devoted to the manufacture of Borg-Warner overdrives for motor vehicles.

During the course of his remarks at this ceremony, Mr. Ingersoll said that the factory would be the largest outside the United States to be employed in the production of this class of equipment. In the near future automatic transmissions would also be turned out.

FIXING THE RESPONSIBILITY

"NEGLIGENCE" IN THE MANUFACTURE AND USE OF TOOLS

Negligence is one of the widest and at the same time one of the vaguest branches of English law. It extends over practically the whole field of human error and deliberate neglect of duty and into practically the whole range of human relationships—employer and employee, manufacturer and consumer, principal and agent, adviser or professional man and client, neighbour, passenger, pedestrian and passer-by. For the manufacturer and employer, however, there are two aspects of this branch of the law which are of particular interest and practical importance, both of which were illustrated in the facts of a recent lawsuit which arose out of an accident to a man at his work.

The workman was engaged on chiselling with a hammer and cold chisel when a piece of metal flew out of the head of the chisel and caused him an eye injury. The accident resulted in the eventual loss of the eye, and the man somewhat naturally sought to recover compensation for his injury. The circumstances of the accident were such, however, that it appeared difficult to find the exact cause, and fix the blame on to any of the persons normally held responsible. The workman himself had done nothing to contribute to the cause of the accident, for he was using his tools in a proper way, for an operation for which they were the correct tools. Furthermore, the operation was one for which it was not customary for eye goggles to be worn, and there was no statutory duty on the employer to see that they were used.

The cause of the accident appeared to be that the head of the chisel was exceptionally hard. It had been in use some two or three weeks only, and had been supplied direct to the employer from the manufacturer, who had a good reputation. The tool had, however, not been inspected by the employer on receipt or after use, when the fact that it had become chipped might have suggested a defect.

It seemed in these circumstances that it would be very difficult to fix upon any act or acts of carelessness to which the accident could be attributed. It is not the law of this country, of course, as is sometimes supposed, that an employer is automatically responsible for any accident at work, but it is necessary for a person claiming damages or compensation for an injury to prove against either the employer, or against some fellow workman (for the employer is responsible for his actions too) some act of carelessness or neglect which has been the immediate cause of the accident. Occasionally too, of course, some person other than the employer, such as a supplier of machinery, may be liable for a defect which causes an accident.

ALTERNATIVE CLAIMS

On this occasion, the injured man commenced an action against his employer and the tool manfacturer in the alternative, and claimed that one or the other (if not both) was in some way responsible for the accident. When it came to trial the Judge decided that in this particular case the employer had done, or omitted to do, nothing which could be called neglect of the duty which an employer owes to his workmen. If, said the Judge, the employer buys tools from a reputable manufacturer, there is no obligation upon him to inspect them when they are received into his store, and many manufacturers would take it as an affront to their methods and the quality of their products to suggest that this should be necessary. Tools are sent out from the factory in the expectation that they will be used by the workman exactly as they are.

Similarly, there should be no necessity for an inspection of a tool after it has been in use for some time to see whether any defects have become apparent. If an employer proves that the tools which he gives his men to use have been bought from a reputable manufacturer and have not been treated on the employer's premises in any way which could occasion defects in them (as in this case by subsequent heating and quenching), he cannot be held responsible for the accident in any way.

In this case, the employer was successful in his defence of the action, for he proved all these things.

THE MANUFACTURER LIABLE

The alternative claim against the manufacturer, however, took a different course. It is the duty of all manufacturers of goods which are intended in the normal course of events to reach the ultimate consumer without an intermediate inspection to take reasonable care in the manufacture, preparation, or "putting up" of the article that it will not cause injury to the consumer.

This duty, it will be noted, is quite independent of any question of warranty or condition made expressly or by implication of law, between the manufacturer as seller and his immediate purchaser. It is a duty owed by the manufacturer to the ultimate consumer, whether he is a direct purchaser or whether he is the last in a chain of half-a-dozen purchasers and sub-purchasers.

This principle was established after much argument in a very well-known case some years ago which went before the House of Lords on appeal from Scotland. A lady became ill after drinking from a lemonade bottle and sued the manufacturers. They made a preliminary objection that they were not liable to her whether or not there was, as she claimed, a dead snail in the bottle. After the principle had been established for all time, as a result of this preliminary argument on the law, that the manufacturer would be liable, it was discovered (so it is said), that there had been no snail in the bottle after all. The rule has, though, been confirmed in many cases since covering all aspects of manufacture.

Once again, however, it must be emphasised that the principle behind the action at law is, all the time, the principle that someone has been lacking in a duty, and has been careless somewhere. It is not enough for a consumer to prove that he had an accident from using some article without showing, at least as a balance of probabilities, that there must have been carelessness in its manufacture.

There are, in fact, three essential ingredients in any claim for negligence at law: a duty on the part of the person against whom the claim is made towards the person making the claim—as the duty of a manufacturer towards an ultimate consumer. Second, some breach of that duty must be established—some act of carelessness or neglect which was the immediate cause of the accident; then, third, somewhat naturally, the person bringing the action must prove that he has suffered some damage.

In the case under discussion, of course, the first and third necessary ingredients of the action were virtually undisputed. The difficulty was to prove the second, some act by the manufacturer of this tool which could have been responsible for the exceptional hardness of the chisel head which caused the accident.

BURDEN OF PROOF

The Judge did not, however, expect the injured man to go so far as to trace the act at the workbench or in the factory which was immediately responsible for the hardening. He accepted the suggestion that it was enough for it to be shown that the tool had been supplied direct to the employer from the factory, and not to have been altered in any way on the employer's premises, for it to be taken as proved that the tool came from the factory with an exceptionally hard head. It was not necessary for the injured man to go further than this to succeed in his action. To show the exact cause of the hardness would be an impossibility, for it might have been caused by one of several possible acts of carelessness in the manufacturer's premises.

In a civil claim, in the civil courts of this country, it is necessary only to convince the Judge (or the jury) on a reasonable balance of probabilities of the essential facts of the claim; it is not incumbent upon anyone seeking to enforce such a claim as this to prove that his case is correct beyond any reasonable doubt, as it is in criminal cases.

Here the Judge was satisfied that not only could some act of carelessness at the maker's premises cause the hardness which led to the accident and injury, but that such an act did do so, and the claim against the manufacturer was accordingly wholely successful. To avoid giving any false impression of the standard of care required of an employer, it may be mentioned that although in this case the employer who had not inspected his workman's tools was held not to be blamed for an accident, it does not follow, and it is not the law, that an employer is free from any obligation to inspect his workmen's equipment.

It is, in fact, one of the normal duties of an employer to arrange for an inspection at proper intervals appropriate to the equipment used, of all plant, machinery, and equipment, which are in use on his premises, and to see that they are serviced, maintained, and replaced at the proper intervals. Any neglect of this duty by the employer, or those in his employ, which causes an accident to a workman will result in a successful claim against the employer for negligence. It seems, though, as is perhaps logical as well as normal practice, that the workman is responsible for his own tools.

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Letters to the Editor

TORSIONAL VIBRATION IN MARINE PROPELLERS

Considerations of Damping Efficiency

SIR, Mr. Duncan, in his letter on page 230 of the issue of August 19, seems anxious to prolong a somewhat unprofitable discussion inasmuch as the truth of the sentence in my article which he finds so controversial, namely that "In marine propeller-shafting systems by far the most efficient device for damping torsional oscillations is the propeller itself," must surely hinge entirely on the definition of damping efficiency.

As I have already indicated, my definition

$$\frac{\Delta E}{E} = \frac{2\pi}{Q} = \frac{2\pi K}{J p}$$

is confined to quantities involving the physical properties of the propeller only. To bring in considerations of relative amplitude and swinging form, implicit in Mr. Duncan's use of the $\frac{\Delta E}{S}$ concept, is to my mind quite irrelevant when discussing the specific damping properties of screw propellers in general, which after all was the sole purpose of my article.

The so-called "missing context" to which Mr. Duncan refers must therefore exist only in the minds of those who attempt to read more into my statement than it justifies.

Finally, Mr. Duncan has no grounds whatever for assuming that "my interest is confined to heavy-oil marine engine installations," since the very nature of my definition of propeller damping efficiency renders it independent of the type of shafting system by which the propeller is driven.

Yours faithfully,

S. ARCHER.

Lloyd's Register of Shipping.
August 30, 1955.

PERSONAL

It is announced that MR. P. G. MASEFIELD, M.A. (Eng.), C.I.Mech.E., F.R.Ae.S., F.I.Ae.S., M.Inst.T., will relinquish his post as Chief Executive of British European Airways Corporation in November to join the Bristol Aeroplane Co. Ltd. In January, he will become the first managing director of the subsidiary company, Bristol Aircraft Ltd. Mr. Masefield served first with the Fairey Aviation Co. Ltd., and then joined the staff of our contemporary, the *Aeroplane*, becoming technical editor at the age of 25. Since the war, when he worked with both the R.A.F. and the U.S.A.A.F., he has held a number of official appointments, joining the staff of B.E.A. in 1949.

The Bristol Aeroplane Co. Ltd. announce that the first directors of their new companies will be (in addition to the appointment of Mr. Masefield, mentioned above):—Bristol Aircraft Ltd.: SIR REGINALD VERDON SMITH, MR. C. F. UWINS, O.B.E., A.F.C., MR. BRIAN DAVIDSON, AIR-COMMODORE F. R. BANKS, C.B., O.B.E., DR. A. E. RUSSELL, C.B.E., MR. R. S. BROWN, MR. W. R. FARNES, O.B.E., and MR. H. J. POLLARD. Bristol Aero-Engines Ltd.: SIR REGINALD VERDON SMITH, AIR CHIEF MARSHAL SIR ALEC CORYTON, K.C.B., K.B.E., M.V.O., D.F.C., MR. BRIAN DAVIDSON, AIR-COMMODORE F. R. BANKS, C.B., O.B.E., DR. S. G. HOOKER, O.B.E., MR. GEORGE HACK, MR. JOHN INNES, O.B.E., MR. R. L. NINNES and DR. E. WARLOW DAVIES. Bristol Cars Ltd.: MR. GEORGE WHITE, MR. BRIAN DAVIDSON and MR. WILLIAM MASTERTON.

MR. H. FOSTER has announced his retirement from the post of head of the engineering section of the Park Gate Iron and Steel Co. Ltd., Rotherham. MR. H. C. WHITE has been appointed chief engineer; MR. F. N. BOOL, works engineer, and MR. H. DEMAINE, electrical engineer. DR. D. F. MARSHALL is works superintendent and MR. D. J. D. UNWIN becomes chief metallurgist.

REAR-ADMIRAL SIR PHILIP CLARKE, K.B.E., C.B., D.S.O., has been nominated for re-election as President of the British Institution of Radio Engineers, for the session 1955–56. MR. G. A. MARRIOTT, B.A.(Cantab.), MR. L. H. PADDLE, MR. J. L. THOMPSON and PROFESSOR E. E. ZEPLER, Ph.D., have been similarly nominated for re-election as vice-presidents. The headquarters of the Institution are at 9 Bedford-square, London, W.C.1.

MR. J. W. TONGE, assistant public relations and publicity officer of the London Midland Region of British Railways since August, 1951, has been appointed public relations and publicity officer of the Region.

MR. JOHN DEXTER, previously a director of Trusteel Corporation (Overseas), Ltd., has been appointed general manager of Maycrete Ltd., Parliament Mansions, Abbey Orchard-street, London, S.W.1, in succession to MR. JOHN LINTOTT, the company's managing director, who has retired owing to ill-health. MR. D. R. STANLEY-ADAMS, previously commercial manager of Shipston Houses Ltd., has become sales manager to Maycrete Ltd.

MR. W. H. GRINSTED, O.B.E., has been appointed technical director of Siemens Brothers & Co., Ltd., Caxton House, Westminster, London, S.W.1.

MR. T. SAMSON has been appointed chief draughtsman of the Trackwork Department of Edgar Allen & Co., Ltd., Imperial Steel Works, Sheffield, 9. He succeeds Mr. H. Borrowdale, whose retirement from this post was referred to in our issue of July 22, page 104.

MR. E. BARNARD, C.B., C.B.E., D.S.O., has retired from his position as deputy secretary in the Department of Scientific and Industrial Research, to which he was appointed in 1945, when the post was created.

DR. THOMAS GIRTIN has recently retired from the chairmanship of Johnson and Sons Smelting Works, Ltd., Brimsdown, Middlesex, to which position he was appointed in 1930. He served on the board of the parent company, Johnson, Matthey & Co., Ltd., from 1921 to 1952, and received the honorary degree of D. Litt. from Leeds University in 1953.

MR. A. W. BRACE, who joined the Aluminium Development Association in 1948, has now taken charge of the surface-finishing work of the Chemical Division of Aluminium Laboratories Ltd., Banbury, Oxfordshire.

Vauxhall Motors Ltd., Luton, Bedfordshire, announce that MR. F. V. BARKER, previously director and factory manager, has been made director of manufacturing and will be in charge of the firm's production, production control, and standards departments; and that MR. H. T. JOHNSON, previously director of forward planning and development, has been made director of planning and facilities, and will assume direct operating responsibility for the forward planning and development, production engineering, sheet-metal production engineering, and plant construction and maintenance departments. MR. A. J. PEPPIATT, acting chief inspector, will report direct to Mr. J. R. Pearson, executive assistant to the managing director.

A number of new appointments to the boards of directors of subsidiary companies of Thorn Electrical Industries Ltd., 105 Judd-street, London, W.C.1, have been announced. MR. S. T. HOLMES, MR. C. E. PAYNE and MR. W. T. WHITE have become directors of Ferguson Radio Corporation Ltd.; MR. A. J. FORD has become a director of Lamp Presscaps Ltd.; MR. A. J. FORD and MR. G. SPARROW have become directors of Manifold Machinery Ltd.; and MR. D. A. NEILL, DR. J. W. STRANGE and MR. G. J. STROWGER have become directors of Smart and Brown Ltd.

Metal Industries Ltd., 60 Buckingham Palace-road, London, S.W.1, announce the following appointments: MR. G. P. BELSHAM to be sole managing director of Brookhirst Switchgear Ltd., Chester; MR. D. W. KENT to be sole managing director of Igranic Electric Co. Ltd., Bedford, relinquishing his seat on the board of Sentinel (Shrewsbury) Ltd.; and MR. E. BRUCE BALL to the boards of Sentinel (Shrewsbury) Ltd., Fawcett, Preston & Co. Ltd., Finney Presses Ltd., and Ferrous Castings Ltd. MR. H. MURRAY TAYLOR and MR. J. LIGHTBODY have been appointed directors of Metal Industries (Salvage) Ltd., and MR. J. BRUCE joins the board of Shipbreaking Industries Ltd. MR. J. R. TWADDLE is chairman of the last two companies.

MR. H. E. G. HARVEY, who has been for four years publicity manager and public relations officer of Ferodo Ltd., Chapel-en-le-Frith, is to become sales manager, and deputy to the chief American executive, of the newly formed British subsidiary of the Webster-Chicago Corporation.

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COMMERCIAL

As a result of the increase in business at home and overseas, the BRISTOL AEROPLANE CO. LTD. have decided to transfer the work of their present Aircraft, Engine, and Car divisions to three new subsidiary companies, to be known as BRISTOL AIRCRAFT LTD., BRISTOL AERO-ENGINES LTD. and BRISTOL CARS LTD. These companies will commence operations in January next. The names of the first directors are given in our "Personal" column.

THE BRISTOL AEROPLANE CO., LTD., Filton House, Bristol, have acquired exclusive rights in the British Commonwealth for the manufacture and sale of the after-burner systems designed and developed by the SOLAR AIRCRAFT CO., San Diego, California, U.S.A. The agreement, which is subject to formal approval by the British Government authorities, provides for an eight-year period of technical collaboration between the two firms, and during this time Solar Aircraft will assist the Bristol Co. in the design and manufacture of after-burner systems for Bristol jet engines.

D. NAPIER AND SON, LTD., The Vale, Acton, London, W.3, have granted manufacturing and marketing rights in the Napier "Spraymat" electrical de-icing system to POWER GENERATORS INCORPORATED, Trenton, New Jersey, U.S.A. The area specifically allotted to Power Generators includes all the eastern States in the United States. A description of this process appeared in our issue of March 19, 1954, vol. 177, page 378.

BIRLEC LTD., Tyburn-road, Erdington, Birmingham 24, have concluded agreements with OTTO JUNKER, G.m.b.H., Lammersdorf, Germany, and the AJAX ENGINEERING CORPORATION, Trenton, New Jersey, U.S.A., for the development and marketing of the mains-frequency coreless induction melting furnace.

The Glasgow branch of ADVANCE MOTOR SUPPLIES LTD. has been moved to larger and more central premises, at 374-376 Argyle-street (Telephone: Glasgow Central 2758).

HEAD, WRIGHTSON & CO., LTD., Thornaby-on-Tees, have moved their Sheffield branch office to 46 Rutland Park, Sheffield, 10.

THE INSTITUTION OF MINING AND METALLURGY removed to 44 Portland-place, London, W.1 (Telephone: LANgham 3802/4) on September 5.

WELMEC CORPORATION LTD., removed to Maypole House, 27/28 Finsbury-square, London, E.C.2 (Telephone: MONarch 9683/5; Telegrams: Welmcor London; Telex: 8473) on August 29, owing to a fire at their former premises in the Strand, in which many of their document files were destroyed. Welmec will be pleased to hear from any firms whose letters have recently been unanswered.

THE UNITED FLEXIBLE METALLIC TUBING CO., LTD., Enfield, Middlesex, have granted the distributing and selling rights in their stainless steel and Monel fused "Toplock" tubing, in respect to the aircraft industry, to BOWDEN (ENGINEERS) LTD., Victoria-road, Willesden Junction, N.W.10. These rights cover both airborne and ground equipments. The Bowden company have set up facilities at their Willesden factory for the production and testing of high-pressure flexible pipe units, incorporating this form of metallic tubing, and such units are now available.

A new company, DAVID BROWN TRACTORS S.A. (PTY.), LTD., has been sponsored by the David Brown Group of Companies for the assembly of David Brown tractors in South Africa. The new company, which has commenced its operations with its headquarters at East London, Cape Province, will also provide after-sales service facilities in all parts of the Union. Suitable factory accommodation is being established on the Gatley Estate in East London. In the first instance, the new company, of which MR. R. M. FOLLY is the manager, will undertake the assembly of wheeled tractors.

LAYCOCK ENGINEERING CO., LTD., Millhouses, Sheffield, have entered into an agreement with KNORR-BREMSE, Münich, Germany, for the manufacture in Britain of the Knorr-Bremse-designed air-braking equipment. The agreement provides for similar collaboration between the two companies in respect to other components designed by the German firm.

SHEPPARD & SONS LTD., Bridgend, have entered into an agreement with the CONSOLIDATED MINING AND SMELTING COMPANY OF CANADA, LTD., Trail, British Columbia, for the manufacture and supply of the molten metal pumping equipment developed by the latter company for handling molten zinc and other metals.

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CONTRACTS

Civil Engineering Equipment. Rock drills, compressors, rippers and air winches are among the civil-engineering equipment, valued £34,000, which HOLMAN BROTHERS LTD., Camborne, Cornwall, have contracted to supply to the Konstruktor and Kokin-Brod organisations in Yugoslavia. Both bodies are to use Holman equipment in the construction of dams and tunnels for hydro-electric projects. The Kokin-Brod hydro-electric scheme is situated on the Uratz River, Serbia, and the Konstruktor organisation is operating at Vlasinaw, on behalf of the hydro-electric department of the Croatian Republic.

Steelworks Equipment. A contract covering the complete electrical equipment for a two-stand temper mill for steel strip, to be erected at Port Kembla, New South Wales, has been entrusted by the Australian Iron and Steel Co., Ltd., to the GENERAL ELECTRIC CO., LTD., Magnet House, Kingsway, London, W.C.2. Each stand of the mill will be driven by a 1,000-h.p. direct-current electric motor, and six other motors, totalling 2,100 h.p., are to be provided for the auxiliary drives. G.E.C. control exciters operating in conjunction with a Ward Leonard system will be included. The contract is valued at £165,000 sterling.

Previous contracts received by the G.E.C. for equipping the Australian Iron and Steel Company's works at Port Kembla include those for supplying the main and auxiliary mill motors, mercury-arc rectifiers, switchboards and control gear.

Centrifugal Pumps. An order made through the Instituto Argentine de Promocion del Intercambio has been placed with WILKINSON RUBBER LINATEX LTD., for 144 centrifugal pumps with Linatex rubber linings. The pumps are for handling abrasive slurries in the Argentine Mining Industry.

Hydraulic Turbines. An order for four hydraulic turbines has been placed by the WASHINGTON POWER CO. (U.S.A.) with the ALLIS-CHALMERS MFG. CO., Milwaukee, Wisconsin. The turbines are to be of the single vertical Francis runner type with welded steel scroll casings; each will be rated at 137,500 h.p. under a 152 ft. head. They are for the Noxon Rapids (Montana) hydro-electric development, and delivery of the first is scheduled for the latter part of 1958.

BRITISH ASSOCIATION MEETING AT BRISTOL

MODEL RESEARCH AND SHIP DESIGN

The annual meeting of the British Association just completed in Bristol is the 117th in the history of the Association and the fifth occasion on which the members have been the guests of the important West Country seaport. The sixth meeting of the Association was held in Bristol under the presidency of the Marquis of Lansdowne who took an active part in the abolition of the slave trade. The Association next visited Bristol in 1875, the President on that occasion being the great engineer Sir John Hawkshaw, F.R.S., President of the Institution of Civil Engineers and builder of the Severn Tunnel. Sir William Crookes, F.R.S., K.C.B., the eminent physicist, was President when the Association held its meeting in Bristol in 1898, and the 1930 meeting was held in Bristol under the Presidency of a botanist, Professor Frederick Orpen Bower, F.R.S. This year's President is Professor Sir Robert Robinson, O.M., F.R.S., a distinguished chemist.

INAUGURAL MEETING

The inaugural meeting was held in the Colston Hall on Wednesday evening, August 31. The proceedings commenced with a procession headed by officers of the British Association and representatives of other associations, followed by officers of Bristol University and the City and County of Bristol. The Lord Mayor of Bristol, Alderman Harry Crook, welcomed the members of the Association and referred, in the course of his remarks, to the progress made in transport since the Association's first visit to Bristol in 1836, this progress having been due mainly to the work of scientists and engineers. The Vice-Chancellor of the University, Sir Philip Morris, also welcomed the Association to Bristol and said that because of the contribution to science made by members of the Association, the University had decided to confer the highest scientific honour in its power on the President of the Association, Professor Sir Robert Robinson and on the President of the Section on Physics and Mathematics, Professor N. F. Mott. The Pro-Vice-Chancellor, Professor W. Beare, then presented the Degrees of Doctor of Science, *honoris causa*, to the Vice-Chancellor for the conferment, and in confering them the Vice-Chancellor referred in eloquent terms to the work of both Sir Robert Robinson and Professor Mott.

Sir Robert then declared the 117th annual meeting of the Association open and delivered his Presidential address, which was entitled "Science and the Scientist." At its conclusion, Lord Adrian, O.M., P.R.S., the immediate Past President of the Association, expressed thanks for the address, remarking in conclusion that Sir Robert had spoken of some of the new paths that would have to be opened and of some of the perils which might lie ahead, but he had cheered all by his sincerity and his faith in the scientific method.

During the course of the Bristol meeting three evening discourses were delivered in the Colston Hall as follows: on Friday, September 2, "Experiments at Great Heights with Free Balloons," by Professor C. F. Powell, F.R.S.; on Sunday, September 4, "Scientific and Dramatic Modes of Thought," by Professor H. D. F. Kitto; and on Monday, September 5, "Stonehenge in the Light of Recent Research," by Mr. R. J. C. Atkinson.

PRESIDENTIAL ADDRESS TO ENGINEERING SECTION

The sectional programmes commenced on the morning of Thursday, September 1, most of the Sections being accommodated in the University Buildings. The meetings of Section G (Engineering) were held in the new University Engineering Building and, as has been the case in recent years, the proceedings were held in two simultaneous sessions, except in the case of the first meeting on Thursday which all members of the Section attended to hear the Presidential Address by Dr. S. F. Dorey, C.B.E., F.R.S., entitled "The Influence of the Engineer on Sea Transport and Trade." We reprint the address, in abridged form, elsewhere in this issue.

Before delivering his address Dr. Dorey was briefly introduced by the former President of the Section, Dr. Willis Jackson, and at the conclusion of the address a vote of thanks was proposed by Mr. H. C. I. Rogers, a vice-president of the Section.

SPACE FLIGHT

Dr. Dorey, who then took the chair, introduced the author of the first paper entitled "The Influence of Space Flight on Engineering and Science." The chairman mentioned that the author, Mr. M. W. Rosen, of the Naval Research Laboratory, Washington, had come to this country specially to deliver his paper. He was acting chairman of the Space Flight Committee of the American Rocket Society and was at present engaged on work connected with the upper-atmosphere research programme of the United States Navy. At the conclusion of his paper Mr. Rosen showed a colour film illustrating the launching of the Viking high-altitude research rocket from the Glenn L. Martin launching area.

The paper and a report of the discussion will be given in next week's issue.

MODEL RESEARCH AND SHIPS

The proceedings of the Section were continued on the morning of Friday, September 2, in two sessions and the first paper taken in session A, at which Dr. Dorey again took the chair, was one by Dr. R. W. L. Gawn, Superintendent of the Admiralty Research Works, Haslar. Dr. Gawn's paper, which was entitled "Model Research and its Application to Ship Design," is reprinted on page 334 of this issue of ENGINEERING. At the conclusion of the paper, the chairman said the author had discussed the difficulties regarding the speed of ships and had called attention to the various factors involved. It was necessary, he said, to make provision for a "pay load" and if high-speed were required great power had to be provided because the power increased as the cube of the speed. One way in which high speed could be attained would be to have an extremely smooth surface; in the case of a submarine with a highly polished surface a speed of 60 knots might be obtained under water. If still higher speeds were needed it would be necessary to take to the air. Commenting on the movement of ships, Dr. Dorey said that in heavy weather the bows of the Queen Elizabeth might move up and down by as much as 80 ft. and to experience such a movement was not at all pleasant. He then invited discussion on the paper.

Mr. S. T. Newing inquired how a uniform speed was maintained on a model in an experiment tank and Dr. Gawn explained that the model was attached to a carriage which travelled along the tank, the resistance to motion being measured by an accurate dynamometer. The distance moved in a given time was recorded as well as the force required to overcome the resistance. The results were accurate to within a small fraction of 1 per cent. He then exhibited the actual propeller model used by Froude in 1873, which he said was the first model propeller ever used in an experiment tank. The propeller was for the cruiser Encounter. For comparison purposes he also showed a model of a recent wide-bladed propeller for an aircraft carrier. Most of the differences between the two designs, he said, had been made to avoid cavitation, although there were other differences.

The next speaker, Mr. M. W. Rosen, asked if the author had made any use of television cameras in his experiments. He also recalled that the late Sir Charles Parsons, many years ago, when considering skin friction and fluid flow, had suggested that the surface of a ship might be made to resemble the scales of a fish. He inquired if any conclusions had been reached on this point.

In reply to the first question Dr. Gawn said the resistance and certain other qualities of a ship were greatly affected by the depth of the water on which it was travelling. To study the effect an experiment tank, fitted with a false bottom which could be raised or lowered to give different effective depths, had been used and he had employed a television camera successfully to see what happened to an object immersed at a depth of 12 ft.

LESSONS FROM NATURE

He regarded the taking of lessons from nature referred to by Mr. Rosen as an important matter and (in this connection) had studied the propulsion of fish. One of the illustrations in his paper showed a whale, which was, of course, a mammal and not a fish. He understood that a whale could travel at 24 knots but only for a few minutes at a time; its cruising speed was nearer 22 knots. Enthusiasts on laminar flow had suggested that a submarine should be shaped like a whale and that had led him to find out what sort of "machinery" a whale possessed. Physiological authorities had informed him that 40 per cent. of the weight of a mammal was represented by locomotory muscles and that 100 lb. of such muscles could generate about one horse-power. With the help of his colleagues he had made experiments to estimate the resistance of a whale and had concluded that the "machinery" power was more than sufficient to give the speed. In the case of the dolphin, the highest measured speed of which was 17 knots, it had been calculated that the power required was four times as much as could be produced by its muscles. It had been pointed out, however, that when a dolphin was travelling its nose and tail moved up and down; he wondered therefore if it might be possible to get better economy by making ships articulated

The final question was from Lieut.-Comdr. Moreland, R.N., who asked whether the author thought there was any future in the hydrofoil boat. In reply Dr. Gawn referred the speaker to Fig. 22 of his paper and said he thought the idea was attractive. It was, however, about 50 years old and there had been comparatively few practical applications so far. A hydrofoil craft, however, was operating a ferry service on Lake Constance and as another vessel of the same type had been ordered for this service he presumed that they were a paying proposition. This was the only practical application of which he was aware and he did not care to express an opinion on the future of vessels of this type.

The chairman then thanked Dr. Gawn for his paper and adjourned the meeting for a brief interval.

To be continued

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METAL BEHAVIOUR IN REACTORS AND UNDER FATIGUE

Similarity of Observed Phenomena

The behaviour of materials within nuclear reactors and the fundamental contribution of crystal structure to metal fatigue were two of the problems discussed by Professor N. F. Mott, F.R.S., in his Presidential Address to Section A (Mathematics and Physics) of the British Association. Professor Mott was speaking on the physics of the solid state and he concentrated

on a discussion of the existence and behaviour of vacant lattice sites in crystalline solids, especially in their relation to the two problems already mentioned.

A vacant lattice site was a point in a crystal structure from which the atom or molecule, which ought to be present in the particular structure, was in fact absent. This concept allowed an explanation of particle migration such as the problem of self-diffusion in solids, notably metals. Such vacancies did occur in a crystal in thermodynamical equilibrium, some of the atoms moving away as a result of heat motion. They could also be formed as a result of bombardment by fast particles and also by the application of cold working to metals.

If two metals were placed in close proximity and were heated sufficiently they welded together, an intermediate region being formed that was composed of an alloy of the parent metals. From this it followed that when the crystal lattice was occupied by two kinds of atom it was possible for them to change places and, moreover, it was known that the higher the temperature the more frequently these changes occurred. If it were true that different atoms could change places, then it was true that atoms of the same kind could also do so. This latter process was called self-diffusion. Proof that such movements occurred and a measurement of the frequency of such atom movements had been obtained by depositing radioactive isotopes on the surface of a metal and then measuring the activity of the body of the metal to discover the rate at which the isotope penetrated. Confirmation of some of the results obtained in this way had been found by making use of "nuclear spin"—the magnetic moment carried by the nucleus of the atom concerned.

Support for the existence of these vacancies was forthcoming in several ways. The energy required to activate the vacancy mechanism was lower than that necessary for other hypotheses concerning particle movement. Then there was the Kirkendall effect which showed that during diffusion in alloys marks embedded in the metal drifted about. There was also the direct evidence of the work in which vacancies were produced artificially and were proved to speed up diffusion.

It was thought that the vacancies produced artificially by bombardment by fast charged particles remained in existence for some considerable time and, as they moved about through the body of the crystal, enabled atoms to change places more easily and at lower temperatures than would be the case without their presence. This radiation damage—where atoms were knocked out of position by charged or uncharged particles—was to be found in both uranium and graphite that had been used in reactors. The effect on the uranium was technically the more serious for it caused the metal to swell and blister as the light isotope was used up, though this behaviour might also be due in part to the presence in the metal of fission products, some of them gases.

One of the more straightforward effects to which vacant lattice sites might be expected to give rise was change in electrical resistance. Attempts to measure these effects had not, however, been entirely successful as discrepancies had been found between observations and the expected effects. The differences were thought to be due to the intense heating generated by bombardment producing regions of local disorder, recognised as thermal spikes, that were much more complicated than simple lattice-vacancy defects. The presence of impurities might also be important, interstitual or displaced atoms or the vacancies possibly being concentrated at the impurities.

Professor Mott then turned his attention to the "urgent and important" problem of metal fatigue, and the way in which the concept of lattice vacancies could be used to help explain this phenomenon. It was known that deformation by cold working produced changes in properties, including changes in electrical resistance, in many ways similar to those which resulted from nuclear bombardment and which could be explained on the basis of lattice vacancies. Under conditions precipitating fatigue failures, localised regions of the solid, which showed up as visible slip bands, were plastically deformed many millions of times. Both experiment and theoretical concepts suggested that in these regions very large numbers of displaced atoms were formed so that, after a time, the crystalline structure was broken as it would be under intense bombardment. It was evident that the continual breaking up of the crystalline structure and the consequent recrystallisation would lead to intense local strains and these strains, perhaps accompanied by considerable local expansion of the metal, were now believed to initiate the fatigue crack. Fatigue failure would then be precipitated by the formation of many lattice vacancies followed by abnormal atom movements.

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Obituary

MR. HAROLD HILLIER, O.B.E.

Marine Auxiliary Machinery

The death of Mr. Harold Hillier, at the age of 64, on August 27, will be greatly regretted by the many people who came into contact with him in many spheres of activity. Shipbuilding was the principal theme of his life, and he started his career by serving an apprenticeship with Vickers-Armstrong, Limited, Barrow-in-Furness. He joined G. and J. Weir, Limited, in 1930, when they acquired the business of the Contraflo Engineering Company, Limited, whose specialties he had played a leading part in developing.

During the second World War Mr. Hillier was a consultant to the Admiralty, and also served on various committees dealing with weapon design. In 1943, his services were recognised by the award of the O.B.E. He was an active member of several learned societies, before whom he read numerous papers dealing authoritatively with such subjects as "Suction Supply Conditions for Pumping Installations," which he dealt with in a paper read before the Institute of Marine Engineers. In 1948, he was awarded the Thomas Hawksley Gold Medal and, in the following year, the Willans Premium for a paper entitled "Feed Distribution and Hunting in Marine Water-Tube Boilers," which was read before the Institution of Mechanical Engineers. In 1953, he was awarded the James Clayton Prize for his contribution to marine engineering, especially in the field of auxiliary machinery, communicated in part in his paper "Scale Formation in Sea-Water Distilling Plants and Its Prevention." This paper was also read before the Institution of Mechanical Engineers.

He was a member of the Institution of Mechanical Engineers and of the Institute of Marine Engineers.

COMPONENT LIFE IN PROPELLER TURBINES

The Nimonic Alloys

We give below an abridged version of a short article compiled by Henry Wiggin and Company, Limited, Wiggin-street, Birmingham 16, *on the life possibilities of Nimonic flame tubes and turbine rotor blades.*

The high-temperature components of gas turbines were at one time regarded as necessarily short-lived because of their arduous operating conditions. Flame tubes frequently failed after only a few hours' running, and have produced temperature peaks in the gas stream which adversely affected turbine-blade life.

Striking extensions of flame-tube life have been made in recent years by improved distribution of the cooling airflow and greater attention to the elimination of local hot spots. When the Vickers Viscount airliner was introduced into British European Airways service in April, 1953, the time between major overhauls of its Rolls-Royce Dart turbo-propellers was 400 hours and the average life of the flame tubes was about the same, with the result that replacements were made as part of the overhaul. When the engine overhaul period was raised first to 600 hours and then to 750 hours, the need to change flame tubes at 400 to 500-hour intervals became a serious disadvantage. Since then, the life of Dart flame-tubes has been progressively raised to 1,050 hours and has kept approximately in step with the engine overhaul period. An immediate target of 1,250 hours for the engine including flame tubes has now been set.

In common with the majority of British designed aircraft gas turbines, the Rolls-Royce Dart flame tubes are of Nimonic 75 nickel-chromium alloy. To prevent wastage of this material during the period when flame-tube design was being improved, Rolls-Royce Limited introduced a salvage scheme whereby the undamaged heads and tails of time expired Dart tubes were cut off and welded to new centre portions. The life of these salvaged units normally exceeds 550 hours.

The Bristol Aeroplane Company, Limited, in developing the Proteus 705 and 755 turbo-propeller engines for the Bristol Britannia airliner, have found that at the end of a stringent 500-hour type test, including more than 283 hours at maximum continuous output, the Nimonic 75 flame tubes of a Proteus 705 were in such good condition that they were immediately approved for further extended service. When the Britannia goes into service with the British Overseas Airways Corporation, there is good reason for believing that the overhaul life of the Proteus will rise rapidly to the 1,000-hour region.

The failure of a turbine blade is a very infrequent occurrence which can usually be traced to a cause such as uneven temperature distribution in the combustion gases or resonance due to unsuitable blade design. In the operation of the Viscount, B.E.A. have experienced few troubles with the Nimonic 80A rotor blades of the Dart engines. The longest operating period completed by any one set of high and low pressure blades has been 1,800 hours (more than 500,000 miles flying), after which an optical inspection showed the blades to be fit for further use.

Encouraging results are also reported from Bristol Proteus development running. After the 500-hour endurance test previously mentioned all turbine blading was in good condition and subsequently saw extended service, notwithstanding the fact that the Nimonic 80 rotor blades of the third and fourth turbine stages had by then completed 1,229 hours of operation. Running times of the Nimonic 90 first-stage rotor blades and the Nimonic 80A second-stage blades were 501 and 826 hours, respectively. This engine employs the casting versions of the Nimonic alloys in its precision-cast segmented stator-blade assemblies, all of which were approved for further service after total running periods in the 600 to 800-hour region.

Book Reviews

SOLVING VIBRATION PROBLEMS

Vibration Problems in Engineering. By S. TIMOSHENKO. Third edition in collaboration with D. H. YOUNG. *D. Van Nostrand Company, Incorporated, 250 Fourth-avenue, New York 3, N.Y., U.S.A.* (8.75 dols.); and *Macmillan and Company, Limited, St. Martin's-street, London, W.C.2.* (65*s.*)

Intricate vibration phenomena have at all times attracted the attention of the physical investigator, and the underlying theory is a wide field well and fruitfully cultivated by the mathematician. In these achievements of pure science and of analytical method the engineer had only a casual interest until extraordinary advances in size, speed and type of prime movers and aircraft together brought in their train a wide variety of important questions concerning vibration. These have only reasonably been solved under the combined impetus of serious failure, elaborate experimental research, and the resources of advanced theory. In all of this work, and especially in the formulation of methods of analysis of problems peculiar to vibrations of mechanical origin, Professor Timoshenko has played a prominent part for many years, as was very clearly indicated by the publication of the first edition of this book, in 1928. A warm welcome is therefore to be extended to the new edition, on which Professor Young's name now appears as joint editor.

The extent of the revision undertaken is perhaps most noticeable in Chapter I, in which 120 pages have been devoted to the fundamental theory of systems having one degree of freedom, the allied matter of balancing the rotating and reciprocating parts of machinery, and an instructive introduction to the phenomena of self-excited vibrations. In a text-book of this kind it is by no means easy to expound the subject of the next chapter, which falls under the main heading "Systems with Non-linear and Variable Spring Characteristics," because the matter is less familiar to engineers and a general solution is really only possible in certain special cases. In their description and exemplification of the numerical and graphical methods which are available for general use, however, the authors have been very successful in smoothing out difficulties and in elucidating those obscure points which are so many pitfalls to the student when his attention is directed to the study of instability in systems with variable spring characteristics. The inclusion of a chapter dealing solely with systems having two degrees of freedom serves the purpose of amplifying the preceding theory of instability by showing how the whirling of a rotating shaft may be influenced by the elastic hysteresis of the material.

In the process of revising the treatment of systems with several degrees of freedom, in Chapter IV, the opportunity has been taken to use the principle of d'Alembert instead of Lagrange's formulae, so that the text may be incorporated into the usual courses of instruction on elementary dynamics. Systems of this class represent schemes in which it is feasible to separate elastic and mass effects, and in this way achieve the reduction of complicated arrangements to idealised combinations having a limited number of degrees of freedom. The final 166 pages of the book, Chapter V, deal with systems which cannot be so reduced, under the heading "Vibrations of Elastic Bodies." This really implies those continuous systems in which the elastic and inertia properties are inseparably interconnected or, more concisely, systems with infinite degrees of freedom. Here the general theory of bars executing longitudinal or transverse or torsional vibrations, whether free or forced, is gradually extended to cover more complicated structural systems, such as, for example, the oscillations of a railway bridge due to the hammer-blow of a locomotive, the vibration of ships, and of flat plates of various shapes. Of the several new topics in this chapter, two merit special notice. The first relates to the combined bending and torsional vibration of a beam which may occur with a non-symmetrical bar of variable cross-section, so that this part of the work has applications in the design of the blades of a turbine, the wings of an aeroplane, and the blades of an airscrew. The other topic is the forced vibration of a beam with various end conditions, where the reader will find guidance on how to proceed when the ends of the beam are not simply supported. In addition to its own wide scope, the book provides numerous graduated exercises, and a wealth of references to further sources of information, and it will undoubtedly meet the requirements of those attending courses of study on the mechanical sciences.

Introductory Applied Physics. By NORMAN C. HARRIS and EDWIN M. HEMMERLING. *McGraw-Hill Book Company, Incorporated, 330 West 42nd-street, New York 36, N.Y., U.S.A.* (6.75 dols.); and *McGraw-Hill Publishing Company, Limited, 95 Farringdon-street, London, E.C.4.* (50*s.* 6*d.*)

As industry becomes more specialised and its machinery more complicated the demand for better trained and more highly skilled operatives increases. The present acute shortage of technicians is a matter of lively concern in this country as well as in the United States and, while it is probable that the supply of university-trained professional engineers cannot be substantially increased, the prospects of increasing the number of scientifically trained workers in industry are more promising. Much has been done and many schemes are afoot to improve the facilities available for technical education, both here and elsewhere, though some time must elapse before they can be fully implemented. Meanwhile more could be done to enable those with latent technical abilities to discover their bent and to quicken the interest of those in the early stages of their formal technological education.

A valuable contribution towards this end is the publication of books such as this "Introductory Applied Physics," designed to provide the groundwork leading to an understanding of the technical problems encountered in industry. It embodies the fruits of a lengthy teaching experience undertaken in close co-operation with representatives of the local industries of California. In it, physics is presented as an indispensable tool which the prospective engineer must learn how to handle. Emphasis is placed throughout on such practical applications as exemplify the most recent developments in technology and certain chapters are devoted almost exclusively to an exposition of current practice in selected industrial fields. The mathematics required has been purposely kept on an elementary level.

The first section of 211 pages is devoted to mechanics and properties of matter, in which mention may be made of the section on precision measurements in industry, whereby interchangeability of parts is secured and mass production methods made possible, and also on the care taken to point out that the most complicated machines can be broken down into a few basic components, nearly all of which were familiar to the ancient Greeks. The next 156 pages are concerned with heat and include good accounts of the processes of heat transfer and of heat engines of all the more familiar types together with those more recently introduced, such as jet engines and rocket motors. Two excellent chapters on refrigeration and air conditioning cover the latest developments very fully with a wealth of numerical data and a number of worked examples. Wave motion and sound occupies only 34 pages but the essential features of wave propagation are clearly conveyed. To illustrate the technical applications of sound waves descriptions are given of sound ranging and prospecting and of the processes of sound recording on, and reproduction from, disc and film. The 54 pages on optics are unduly sketchy, comprising a brief account of light sources and photometry, very little geometrical optics, with nothing on the telescope and a bare mention of the microscope, while physical optics is dismissed in a paragraph or so on dispersion and polarisation. The remaining 220 pages deal more comprehensively with magnetism and electricity, electronics and atomic physics. The fundamental principles of direct and alternating currents, electromagnetism and electromagnetic induction are clearly explained and the accounts of generators, motors, and the generation and distribution of electric power are well presented. Various electronic devices are described together with their mode of operation. The chapter on the principles of electrical communication covers the telegraph, the telephone and radio broadcasting, but the mere mention of television is hardly adequate. In the concluding chapter the nature of nuclear energy is outlined together with some indications of its uses for military and industrial purposes.

Following a review summary of the contents of each chapter, useful sets of questions and problems are provided, to some of which solutions are given. The items in the selected list of films and other aids to teaching, contained in an appendix, are all of American origin but similar material would not be difficult to find in this country. The text is lavishly illustrated, almost the only illustration that falls below the prevailing high standard being Fig. 22.20. In a book of this character some unduly sweeping or over simplified statements are inevitable (such as that on page 368), but these are comparatively few and none is too seriously misleading. Among the few errors noted were "John" instead of "James" Clerk Maxwell on page 403 and "John" instead of "Ambrose" Fleming on page 621. The simple style of this book makes it easy to assimilate while its direct method of approach should prove immensely stimulating to students in the early stages of their training.

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BRITISH NUCLEAR ENERGY CONFERENCE, LONDON MEETING

The first meeting of the British Nuclear Energy Conference, the establishment of which was referred to on page 716 of our issue of June 10 last, will take the form of a symposium of lectures and will be held at the Institution of Civil Engineers, Great George-street, London, S.W.1, on Wednesday, November 30, 1955, from 2.15 p.m. to 8.15 p.m. There will be an interval for tea from 4.45 p.m. to 5.15 p.m.

The meeting will be opened by the chairman of the Conference, Sir Christopher Hinton, M.A., F.R.S., M.I.Mech.E., and four lectures will be delivered, comprising: "The United Kingdom Atomic Energy Project," by Sir John Cockcroft, K.C.B., Hon. M.I.Mech.E., F.R.S.; "The Place of Nuclear Energy in United Kingdom Power Development," by Mr. V. A. Pask, C.B.E., M.I.Mech.E., M.I.E.E., and Mr. J. C. Duckworth, B.A.; "The Use of Research Reactors in Nuclear Power Development," by Mr. H. J. Grout, B.Sc., A.M.I.Mech.E.; and "Health and Safety in a Nuclear Power Industry," by Dr. A. S. McLean, M.B., Ch.B., D.I.H., and Dr. W. H. Marley, M.Sc.

Owing to the limited accommodation available, attendance at the symposium will be restricted to members of the five institutions participating in the Conference and members of the organisations concerned are asked to apply to the secretaries of their respective institutions as promptly as possible. Advance copies of the lectures will not be available.

The secretary of the Conference is Mr. A. McDonald, 1-7 Great George-street, London, S.W.1.

BOOKS RECEIVED

Some of the books noticed here are selected for extended review in ENGINEERING.

Centrifugal and Other Rotodynamic Pumps. By HERBERT ADDISON. Second edition. *Chapman and Hall, Limited*, 37 *Essex-street, London, W.C.*2. (50*s.*)

In the note that was published in these pages on the first edition of this book, the reviewer said: "The author has made a thorough investigation into the subject of centrifugal pumps . . . his similes reveal an ability to present what has been regarded as a difficult subject in a way which will be readily grasped." The original style has been retained in the second edition, and the necessary additions made to bring the material into line with modern progress. Mixed and axial flow pumps are dealt with and some particular installation problems described. Nomograms, conversion tables and a considerable bibliography are included.

Diesel Maintenance. A Practical Guide to the Servicing of the Modern Automotive Diesel Engine. By T. H. PARKINSON. Edited by DONALD H. SMITH. Fourth edition. Published for "Motor Transport" by *Iliffe and Sons, Limited, Dorset House, Stamford-street, London, S.E.*1. (12*s.* 6*d.*)

With more and more Diesel-engined vehicles on the road, the garage and service station have to be prepared to handle them. The fourth edition of Mr. Parkinson's book has been thoroughly revised to give information regarding the latest types to be met and how to overhaul, recondition and test them. Sections are devoted to the various ancillary equipment, such as fuel pumps and injectors, and the whole is intended as a practical guide to the service mechanic. It is published as a companion volume to *The Modern Diesel*, which deals with principles and reviews the range of engines in current use.

Applied Thermodynamics. By EARLE B. NORRIS, ERIC THERKELSEN and CLARENCE E. TRENT. Third edition. *McGraw-Hill Book Company, Incorporated*, 330 *West* 42*nd-street, New York* 36, *N.Y., U.S.A.* (7.50 dols.); and *McGraw-Hill Publishing Company, Limited*, 95 *Farringdon-street, London, E.C.*4. (53*s.* 6*d.*)

Originally published under the title of *Heat Power*, this volume, written by three professors of engineering, is intended for the student. It may be divided into three main headings: internal-combustion engines, including aero engines and turbo-jets; steam plant, both boilers and engines; and compressors and refrigerators. In each case the full fundamental theory is given as well as practical examples. Each chapter concludes with a set of example problems.

Colliery Year Book and Coal Trades Directory, 1955. Thirty-third edition. *The Louis Cassier Company, Limited, Dorset House, Stamford-street, London, S.E.*1. (30*s.*)

As heretofore, much detailed information on the coal-mining and allied industries is given in the new edition of this year book and directory, and, in addition, some new features have been introduced. There are particulars of the principal coal mines in the United States as well as data for collieries in Western Europe, a feature first introduced in 1953. Another new item is a coal-industry cinema-film guide, and considerable space has been given to the Mines and Quarries Act, 1954. For easier reference the mines index and the statistical sections are separately coloured on the fore-edge of the book.

Annual Report (Technical) of the Central Board of Irrigation, India, 1950, Vols. I and II. Edited by S. L. MALHOTRA. *Central Board of Irrigation and Power, Curzon-road Barracks, New Delhi, India.* (No price given).

This report contains an account of the meetings of the Board, its research committee and technical sub-committees; summarised reports from various research stations; technical proceedings of the research committee, in the following main groups: theory and practice of model experiments, hydraulic works, water power, hydrology, soil science and soil mechanics, theory of flow and design of channels, irrigation practice, navigation practice, and water utilisation projects.

Electrical Measurements and Measuring Instruments. By E. W. GOLDING. Fourth edition. *Sir Isaac Pitman and Sons, Limited, Pitman House, Parker-street, Kingsway, London, W.C.*2. (40*s.*)

The first edition of this book was published in 1933 when it was originally the author's intention briefly to cover the syllabus of the B.Sc. (Eng.), City and Guilds (Final) and Institution of Electrical Engineers' examinations. This scheme was, however, modified to meet the requirements of electrical engineers in general and now a thorough revision has been made to deal with the important developments which have recently taken place. These include changes in symbols and nomenclature; an expansion of the treatment of M.K.S. units and rationalisation; in the study of dielectrics and in the inclusion of resistance measurements for determining non-electrical quantities. Developments in illumination, high-voltage measurements and cathode-ray oscillography have also led to modifications. Descriptions of the instruments themselves have been revised and a new chapter on "Electronics and Electronic Measuring Devices" has been included.

Gas Turbines for Aircraft. By IVAN H. DRIGGS and OTIS E. LANCASTER. *The Ronald Press Company*, 15 *East* 26*th-street, New York* 10, *N.Y., U.S.A.* (10 dols.) (Reviewed on page 298, in the issue of September 2.)

Aviation English: Méthode d'Anglais a l'Usage des Personnels de l'Aéronautique Militaire et Civile et des Exploitants des Transmissions. By S. HUMBERT. In two volumes. *Dunod*, 92 *Rue Bonaparte, Paris*, 6e. (No price given.) (Reviewed on page 298, in the issue of September 2.)

Les Applications Pratiques de la Luminescence. By M. DÉRIBÉRÉ. Third edition. *Dunod*, 92 *Rue Bonaparte, Paris*, 6e. (3,300 francs.)

This third augmented edition is a comprehensive treatise on the practical application of luminescence. Principles are stated and discussed, and methods are elaborated relating to the practical application of luminescence in testing and/or analysing pharmaceutical and chemical products, foodstuffs, etc. It contains plates showing the advantages and the use of fluorescent light in the examination of ancient and modern documents. Cathode rays and X-rays are also discussed as well as the latest "optical bleaches."

Die Dampfturbinen: Theorie, Berechnung und Konstruktion für Studium und Praxis. By Prof. Dipl.-Ing. C. ZIETEMANN. Second edition. *Springer-Verlag, Reichpietschufer* 20, *Berlin, W.*35. (43·50 D.M.)

This book, which was first published in 1930, is a revised and enlarged second edition. Whilst this work, according to the author, is not intended to replace or supersede the classical work by Stodola, it is intended to give guidance to the student and less experienced engineer in the design and calculation of steam turbines. A number of worked examples of the calculation of steam turbines and their component parts are given and it is stated that these examples are taken from actual plants. Various methods of control are discussed, and a number of sectional arrangement drawings of turbines by various makers are reproduced. Back-pressure, exhaust and bleed-off turbines, as well as steam accumulators are discussed.

Gestaltung von Fahrzeuggetrieben. By Dr.-Ing. HANS REICHENBÄCHER. *Springer-Verlag, Reichpietschufer* 20, *Berlin, W.*35. (26·40 D.M.)

This work deals with the design and construction of change-speed gears for motor vehicles. It is intended for engineers familiar with the mathematics of differentiation and integration calculations. The main purpose of the book is to describe change-speed gears and their elements which have given satisfaction in practice. It discusses the choice of stages of the gearbox, the consideration to be given to the ratio of the top gear and the bottom gear, acceleration and maximum speed, and the various methods of operating the gears. A special chapter deals with the calculation of tooth gearing. Finally, hydraulic drives are extensively discussed.

Mécanique-Physique Générale. Aide-Mémoire Dunod. By M. DENIS-PAPIN. Fifth edition. *Dunod*, 92 *Rue Bonaparte, Paris* 6e. (480 francs.)

This handbook in the *Aide-Mémoire* series is in its fifth edition. It covers the field of physical mechanics in general and is drawn up for advanced scientific and technical students, students of higher and specialised mathematics, engineers and physicists. In addition to revising and enlarging the contents of the previous edition, any matter duplicating parts of other handbooks in the same series has been eliminated. The subject is treated under the main headings: vectors in the study of mechanics, physics and electricity; kinematics; statics; dynamics; gravity, including the states of equilibrium and movement; heat and thermodynamics; mechanics of fluids; displacements and elastic and electromagnetic vibrations; cosmography; units of measurement; and tables of functions. There is a supplement of usual tables and formulae and diagrams are provided to illustrate the text.

TRADE PUBLICATIONS

Copies of any of the following trade publications are obtainable from the addresses given, though distribution is sometimes restricted.

Wire-Cutting Shears. INDUSTRIE-DIAMANTEN, G.m.b.H., Bahnhofstrasse, 42, Zürich 1, Switzerland. (Agent in Great Britain, O. A. Volkmann, 3 St. Augustine's-road, Birmingham, 16.) Handheld shears for cutting wire. The cut ends are square, and hard steel wire can be cut. The movable blade is operated by a rack from the hand-lever. Blades are standardised, reversible and interchangeable. Each blade has eight cutting edges. Illustrated leaflet.

Roofing Material. NURALITE SALES LTD., 3-4 Whitehall-place, Gravesend, Kent. Flexible waterproof roofing material of laminar construction composed of asbestos and bitumen. May be cut, joined or moulded, and becomes pliable and slightly extensible on heating; suitable for applications in which zinc or lead are at present used, such as flashings for chimneys, etc., guttering, and ridge and hip capping. Illustrated booklet with sample "Nuralite" insert. Also competition announcement.

Internal and External Grinding Machine. RUDKIN AND RILEY, LIMITED, Cyprus-road, Aylestone, Leicester. Grinding machine capable of dealing with work from 0·04 in. to 3½ in. internal diameter, and from 0·04 in. to 3 in. external diameter. The maximum length between centres is 7 in. The machine has an automatic reciprocating traverse for the grinding carriage, with a maximum stroke of 4 in. Illustrated folder.

Machine Tools in Stock. SOAG MACHINE TOOLS, LIMITED, Juxon-street, Lambeth, London, S.E.11. List of a variety of machine tools in stock, including centre, turret and special-purpose lathes; vertical and horizontal borers; milling, sawing, slotting and grinding machines; gear cutters, planers and shapers; and drilling machines. Illustrated brochure.

Railway and Road Vehicles. METROPOLITAN-CAMMELL CARRIAGE AND WAGON CO. LTD., Vickers House, London, S.W.1. Descriptions of passenger and goods rolling stock made for use in many countries, brief account of factories, export contracts, and production of road passenger vehicles. Illustrated booklet.

Electric Traction. ENGLISH ELECTRIC CO. LTD., Queens House, Kingsway, London, W.C.2. Electric and Diesel-electric locomotives supplied to railway systems in various parts of the world; brief technical data, illustrations and descriptions of duties performed. Illustrated booklet.

Tank Fittings. WHESSOE LTD. 25 Victoria-street, London, S.W.1. Shand and Jurs' fittings made under licence, including gauges and level indicators, swing line equipment, venting equipment, flame arresters and drains. Pamphlet No. 66 (replaces No. 49).

"Oildag" Colloidal Graphite. ACHESON COLLOIDS LTD., 18 Pall Mall, London, S.W.1. Description of oildag and uses for assembly and running-in, lubrication of bearings, etc., and hot metal-working operations. Illustrated leaflet.

Soot Blower Equipment. CLYDE BLOWERS LTD., Clydebank. Descriptions of soot blower equipment for land water-tube boiler installations, economic shell-type boilers, and marine water-tube boilers. Three illustrated pamphlets.

Bottle Trolley. BROADWAY EQUIPMENT LTD., Parway House, 194–196, Finchley-road London, N.W.3. Trolley with retractable axle for carrying gas bottles for welding plant. Including fastening gear and tool box. Leaflet.

Barrel Finishing Compounds. LACRINOID PRODUCTS LTD., Gidea Park, Essex. "Lacron" chips and five finishing compounds to cover all different materials treated by the Lacromatic barrel-finishing process. Illustrated brochure.

Weld Inspection. ASSOCIATED OFFICES TECHNICAL COMMITTEE, 67 King-street, Manchester, 2. "Rules for Inspection and Tests of Welds in Pressure Pipelines." Booklet giving requirements approved by five insurance companies.

Torsional Vibration Damper. HOLSET ENGINEERING CO. LTD., Turnbridge, Huddersfield. "Holset" torsional vibration damper for prime-movers. Description and applications. Leaflet No. 102.

Speed Reducers. ELECTROPOWER GEARS LTD., Kingsbury Works, Kingsbury-road, London, N.W.9. Geared motors and reduction gearboxes. All sizes and speeds. Leaflet.

Drawing Office Equipment. W. G. PINNER & CO., 1 York-road, Birmingham, 16. Instruments and equipment for the drawing office. Folder.

INFLUENCE OF THE ENGINEER ON SEA TRANSPORT AND TRADE

STERN-WHEELER TO NUCLEAR-POWERED SUBMARINE

By S. F. Dorey, C.B.E., D.SC., F.R.S.*

In his presidential address on September 1, 1955, to Section G (Engineering) of the British Association at its Bristol Meeting, Dr. Dorey traced the growth of marine engineering from the earliest use of steam propulsion to the ships of to-day powered by gas turbines and nuclear reactors. His address, abridged, is given below.

The seaports of the West Country will long be famed for the part their seafarers and small but sturdy ships played in voyages of discovery. In the absence of foreign competition however British shipowners were complacent and the stagnant conditions of those days removed incentive both in shipbuilding and ship operation.

Throughout the Eighteenth Century naval architecture remained static and improvements were negligible in both the speed and size of sailing ships. At the end of the period, the Americans, having achieved political independence, were the first to break with tradition in the design and construction of merchant ships. They exploited the merits of fast, sleek sailing ships in place of lumbering heavily armed merchantmen, and this move soon proved a technical and commercial success.

In 1816, they were the first to establish regular sailings and a monthly service between New York and Liverpool commenced and by the 1840's the American merchant fleet had increased until it was the second largest in the world and comprised sailing ships which were second to no others. Moreover, their 50 years' sole experience in the construction and development of speedy clippers gave them an almost unsurpassable lead in sail.

INTRODUCTION OF THE STEAM ENGINE

Pioneer engineers had other ideas of the best means for propelling ships, and as early as 1801, Symington patented his method of constructing a steam engine which provided rotatory motion at a crankshaft through a piston rod and connecting rod, thereby eliminating the conventional lever or beam. A horizontal single-cylinder double-acting engine of this type was used to drive the crankshaft of the stern paddle-wheel steamer Charlotte Dundas. The successful trials of this first practical steam-boat proved the potential merits of steam propulsion and inspired engineers on both sides of the Atlantic.

In 1807, Fulton employed British steam machinery to propel the paddle steamer Clermont on the Hudson River. This ship demonstrated the advantages of steam propulsion over sail for navigation on inland waterways, and early American developments concentrated on this aspect. In 1811, Bell introduced the famous paddle steamer Comet into service between the ports of the Firth of Clyde. Shipbuilders quickly appreciated the qualities of this ship and comparable vessels were soon building at all major British ports. With limited sheltered waters these steamers were used largely for coastal service and by 1826 appeared on the London to Portugal and Dublin to Bordeaux routes. The working pressures of boilers were below 5 lb. per sq. in. and coal consumption of the steam machinery was little better than 10 lb. per i.h.p.-hour. In consequence the machinery and fuel occupied a large proportion of the available space in the ships and severely limited the freight-carrying capacity. Nevertheless, these steamers were a success and in the 1830's few steam-ship companies lacked financial support. Owners generally ploughed profits back into the companies and rendered a valuable service to commerce and steam-ship development by increasing their total tonnage with new construction. The burden of this practice was heavy but eventually proved sound policy, when, in 1837, the Government contracted private companies for the sea-carriage of mails.

Shipowners and engineers aimed at the conquest of the Atlantic by steam and to compete with the fast sailing-ships for the steadily growing passenger and freight traffic. By 1838, improvements in steam machinery had reduced coal consumptions to 5 lb. per i.h.p.-hr. and the total fuel necessary for the crossing could now be carried. In that year the Sirius steamed continuously from Cork to New York in 19 days, but within a few hours of her arrival the Bristol-built Great Western arrived having steamed continuously from her home port on a maiden voyage of only 15 days. The latter ship undoubtedly stole the thunder and Sir John Rennie considered, at that time, that her performance was such that there seemed no bounds to the extension of steam navigation. That the first voyage of the Great Western was in no way abnormal is evident from her eight years' service prior to being broken up; a period in which she made 74 double crossings of the Atlantic with average outward and return times of 16½ and 13¼ days respectively.

IRON CONSTRUCTION AND SCREW PROPULSION

Constructional engineers and forge-masters had also been active since 1815 when a small sailing-ship with a wrought-iron hull plied the Mersey. This was followed three years later by an iron passenger-boat, Vulcan, which commenced operation on the Firth of Clyde, canal, while an iron steamer, Aaron Manby, navigated from Thames to Seine in 1822. Such small iron vessels were initially pre-fabricated in sections at the forges of the Midlands for transportation and assembly at the ports. As confidence grew, larger ships were built in the shipyards, and by 1850 Lloyd's Register Book contained the names of no less than 100 iron ships, more than half being steamers. Their size was generally below 550 tons, but the then colossal iron steamer Great Britain, of 3,618 tons, had already been in service for five years. Although a commercial failure, this venture was in many ways a technical success, establishing an inevitable trend to larger ships for ocean service. Moreover, her capacity to carry 1,000 tons of coal, 1,200 tons of cargo and 260 passengers represented a marked advance in the capabilities of the steam-ship.

The Great Britain was also the first large screw steamer to enter ocean service, and, although at an early stage of development and therefore less efficient than paddles, screw propulsion proved superior, as heavy seas could damage paddles and render them inoperative. The Admiralty were prejudiced against both iron construction and screw propulsion and on their instructions the early Cunarders which carried the Atlantic Mails were wooden-paddle steamers. It was not until the 1860's when a reduction in the hazards of fire, grounding and collision had been attributed to iron construction, that relaxations were permitted. At the same time experiments instituted by the Admiralty had improved the performance of propellers to a stage that these, too, could be accepted.

Although developed to a reasonable state of reliability, single-expansion engines exhausting to surface condensers showed little improvement in fuel consumption. Steamers were, therefore, incapable, of making the long voyages to Australia via the Cape, and completion of the journey in stages was impracticable. Two alternatives were tried and both these were originated by the famous engineer Brunel and the equally eminent ship designer Scott Russell. The first was an iron ship, Victoria, of 3,000 tons, equipped with a small steam-engine driving a two-bladed propeller through gearing. The hull of the vessel was of greatly advanced design and a speed of ten knots could be obtained when the engines were operating, while six knots was maintained under sail. A voyage of 60 days from Gravesend to Adelaide won the Colonial Prize of £500 for the fastest journey. The second ship, the phenomenal Great Eastern, never confirmed the theoretical considerations on which her construction was founded. Brunel was of the opinion that this ship of 32,000 tons and carrying 10,000 tons of coal could steam the round trip to Australia without recoaling and, at the same time, carry sufficient cargo and passengers to provide a handsome return. The complete commercial failure of this ship is a well-known story but she must be credited with laying more than 100,000 miles of cable, which established communications across the Atlantic and offered shipowners a convenient means of arranging cargoes and controlling the voyages of their steamships.

COMPOUND ENGINES AND USE OF STEEL

It was abundantly clear that increased trade and traffic with the Far East and in the Pacific hinged on the improvement economy of the main machinery of steamships. By 1854 advancement in the design and operation of iron boilers made working pressures of 25 lb. per square inch possible and also enabled Elder and Randolf to produce a practical compound engine in which the steam underwent a second stage of expansion. The first engine installed in the Brandon showed a fuel consumption of 3¼ lb. per i.h.p.-hr., but early engines of this type suffered from want of reliability. Two years later the Pacific Steam Navigation Company put two paddle steamers, Inca and Valpariso, into service and each was fitted with compound engines. Three other ships of this company were then re-engined with this type and one of these ships, the Bogota, displayed a 50 per cent. fuel saving after re-entry into service. Up to 1866 Elder and Randolf alone had built 48 sets of compound engines which were mainly operating in the Pacific. At the same time the P. and O. Company had ten ships propelled with compound engines in general operation and the Blue Funnel Line had three. The latter company were able to run 8,500 miles from England to Mauritius without recoaling.

A century ago Bessemer patented the converter process for the manufacture of steel and the products of early practice were used almost exclusively for hull construction, the quality not being found consistently reliable for boiler-making. Nevertheless, valuable experience was gained in the manipulation of steels in the shipyard and hastened the extensive use of the high quality and cheaper materials made available in quantity by the later Siemens Martin open-hearth process. Steels led to a minor revolution in shipbuilding and boiler and machinery construction. The superiority of steel over wrought iron permitted a 25 per cent. reduction in the scantlings of principal component parts representing a saving in weight of over 100 tons per 1,000 gross tons of ships, as well as reducing power plant weights. These savings were important at a time when steamers had to carry large quantities of fuel. An even greater effect of steel construction was evident in boiler practice, however, for within a few years working pressures increased threefold and brought about improved economy and reduction of unit size.

During the 1880's triple expansion superseded those of compound type on the Atlantic. At the same time multi-screw propulsion was adopted to meet the demands of steam-ship companies for greatly increased power of single ships. Moreover, competition was keen for the trade and passenger traffic, and speed and size of ships were matters of international rivalry. It was these events which led to the realisation of Brunel's conception when he planned the Great

* Chief Engineer Surveyor, Lloyd's Register of Shipping.

Eastern, but 40 years of engineering progress had to pass before similar ventures could be undertaken without the risk of complete commercial failure.

STEAM TURBINES

Of the liners fitted with triple-expansion engines the twin-screw Campania of 12,950 tons and 601 ft. in length, may be quoted. Built in 1893 the engines developed a total of 31,000 i.h.p. and propelled the ship at 22 knots. About the same time the quadruple-expansion engine was evolved and offered further economy in operation. The largest steam reciprocating engines built were of this type and engined the liner Kaiser Wilhelm II. 43,000 i.h.p. was obtained with steam raised at 225 lb. per sq. in. pressure in 14 double-ended and seven single-ended cylindrical boilers. Power/weight ratios of large reciprocating machinery installations ranged from 6 to 7 i.h.p. per ton and the total weight of the quadruple machinery of the Deutschland weighed no less than 5,670 tons for 38,900 i.h.p. In addition, unpleasant hull vibrations were excited by the heavy reciprocating masses and were detrimental to the comfort of the passengers. For these reasons steam reciprocating machinery was not entirely suitable for high-powered liners and the limit of total power of the ship had been attained so far as these prime movers were concerned.

It was not surprising, therefore, that Parson's Turbinia was acclaimed as an outstanding triumph, for it offered the solution to these problems. Nine years later, in 1905, the 30,000-ton liner Carmania was engined with steam-turbines of 21,000 s.h.p. and after a further two years the quadruple-screw liner Mauretania was completed with single reduction geared turbines of 70,000 total s.h.p. A speed of 24½ knots won this liner the Atlantic record which she retained for a 22-year period signifying that she represented the end of the first era of national and international rivalry for the largest and fastest ship afloat.

During this era shipowners had also been able to equip their fleets with ships of increasing size, for expanding trade had always proved their speculation sound. The British Merchant Fleet had increased by no less than 5,000 ships in half a century and in the latter half of this period other nations had recognised the achievements of British engineering and built up fleets of merchant steamships for their own purposes. In consequence, there was now a tendency to adopt economical sizes of each type of merchant ship and many wondered whether a ship like the Mauretania could be a paying proposition. Further, trans-ocean cables which had been laid by steamships and the recently introduced wireless telegraphy enabled ships to operate more econmically by reducing the delays at ports. Owners were, therefore, able to prearrange cargoes and ascertain the exact whereabouts or progress of the ships in their fleet. On the other hand, the rapid growth in world merchant ship tonnage and the availability of telegraphic communication stimulated competition and full cargoes were not readily obtainable.

For the engineer the conquest of the trade routes by steam navigation was complete and the steam reciprocating and turbine machinery had attained a high degree of reliability with reasonable economy. His role had therefore changed from a pioneer to a consolidator; adapting, modifying and developing the various types of machinery at his disposal to meet the many requirements of shipowners and operators.

USE OF OIL FUEL

By the end of the Nineteenth Century the supplies of heavy oil fuels were sufficient to warrant consideration as an alternative to coal for firing the boilers of steamships. The advantages of liquid fuels in respect of transportation, handling and storage were obvious, but it was not until 1894 that an oil-burning steamer, the Baku Standard, entered sea service. In the first half of this century coal burning has been almost entirely replaced by oil burning for sea-going steamers and so far as new construction is concerned, the change-over is virtually complete.

The next landmark in marine engineering was the oil engine which was introduced as a main prime mover for ocean-going merchant ships in 1910, when the 1,179-ton tanker Vulcanus was completed and engined with a Werkespoor six-cylinder 4 S.C.S.A. Diesel engine of 500 b.h.p. rating at 200 r.p.m. It may be of interest that this engine was still operating satisfactorily when the ship was sold for scrap in Japan, 20 years later. A greater advance was represented by the Burmeister and Wain Diesels which engined the twin-screw motorship Selandia of 5,000 tons. Completed in 1912 each eight-cylinder 4 S.C.S.A. engine developed 1,050 b.h.p. at 140 r.p.m. and showed that the problems of high-powered oil engines were being effectively overcome. This installation was so revolutionary as to attract the attention of the world. Sir Winston Churchill, then First Lord of the Admiralty, visited the ship and examined the machinery layout. On this occasion he said that . . . "it was a pleasant duty for him to congratulate Denmark, the ancient seafaring nation which had shown us the way and taken the lead in a venture that will form an epoch in the development of shipping." As on many other occasions, history has confirmed the validity of his shrewd judgment. The Selandia was in operation until 1942 when she was wrecked. During the life of this ship the oil engine had become the predominant prime mover for new merchant ships constructed in the world, and by 1939 engined more than one-quarter of the total number of ships afloat.

Following the 1914-18 war, shipowners were faced with the problem of rebuilding their total tonnages to make good the losses during the hostilities. They had struggled to achieve this aim without subsidy when trade eased and competition became keen to secure freights. Reductions in fuel costs were of vital importance and it was this aspect which received the attention of engineers. The triple-expansion steam engine then operating with saturated steam supplied by Scotch boilers of 200 lb. per sq. in working pressure, offered fuel consumptions of 1·6 lb. of coal or 1·1 lb. boiler oil per i.h.p.-hour. Steam-engine makers soon developed improved designs incorporating such features as poppet valve gear and uniflow exhaust of cylinders, and capable of operating with superheated steam at total temperatures approaching 700 deg. F.

The inability of the reciprocating engine to utilise all the possible expansion of the steam due to limits imposed on the size of the L.P. cylinders, was overcome by the fitting of exhaust steam-turbines. This was no new feature, for Parsons used a reaction turbine supplied with exhaust steam from two reciprocating engines and driving an independent shaft directly, in the triple-screw steamship Otaki completed in 1908. Before this arrangement was superseded by the geared-turbine for passenger ships, a number of other installations were completed, including those of the Olympic and Titanic.

The arrangement first fitted in a single-screw ship in 1926 was the Bauer-Wach system, in which the drive from the turbine was transmitted through double-reduction gearing and a fluid-coupling back to the reciprocating engine main shaft. Other manufacturers preferred electrical to mechanical transmission and in these cases the exhaust steam turbo-generator with either a.c. or d.c. output supplied an electric motor mounted at a convenient position on the main propulsion shafting.

Reheating of the steam before admission to the medium-pressnre cylinder of the engine also offered appreciable improvement in performance. The direct method of raising the conditions of the high-pressure exhaust used a heat exchanger supplied with superheated steam direct from the main boiler unit. As an alternative, an exhaust turbine was used to drive either a d.c. generator which supplied electrical heating elements or a steam compressor.

Each of the improved steam reciprocating installations had its own particular merits and champions. Fuel consumptions of just under 1 lb. coal or 0·8 lb. oil per i.h.p.-hour could now be offered and these represented appreciable savings in overall fuel costs. Nevertheless, progress in the oil-engine field had been so marked as to offer a serious rival to the steam reciprocator.

THE DOXFORD ENGINE

In 1914 Doxford and Sons, Limited, of Sunderland, ran endurance trials on a single-cylinder, two-stroke cycle, heavy-oil engine, which embodied the opposed-piston principle and developed 450 b.h.p. at 125 r.p.m. This represented a major advance in the power output of a single cylinder. During the 1914-18 war the performance of both four-stroke and two-stroke oil engines progressed rapidly and this was assisted by the adoption of solid injection of the fuel: an important departure from the Diesel principle.

By 1921, two-stroke types of four cylinders were providing 3,000 b.h.p. on a single screw, but four-stroke types nevertheless predominated in marine practice. Four years later, double-acting engines of the latter type displayed single cylinder outputs of 1,100 b.h.p. The twin-screw motorship Gripsholm, for example, was directly propelled by two six-cylinder engines of this type, 33 in. in bore and 59·1 in. stroke, with a total output of 13,500 b.h.p. at 125 r.p.m. Doxford's soon challenged this achievement by building engines of the two-stroke type described and the 5,000 total b.h.p. represented 1,250 b.h.p. per cylinder.

At this time many of the service problems experienced with the two-stroke oil engines had been surmounted and a number of engine builders who had previously favoured four-stroke types now regarded the former as a better proposition. In consequence the passenger liners Britannic and Georgic, completed in 1930 and each fitted with two ten-cylinder engines of 20,000 combined b.h.p., represented a peak in the progress of the four-stroke type. Thereafter preference for the various two-stroke engines prevailed until the present day, when they form no less than 80 per cent. of the main oil-engines fitted in ships. Further, the fitting of Buchi superchargers to engines of the four-stroke type, although giving improved performance, had little effect on the predominance of the two-stroke engines.

By 1934 two-stroke engines were supplying up to 7,000 b.h.p. on a single screw and the replacement of cast-iron bed plates, entablatures and columns by welded fabrications in mild steel did much to reduce the weight and size of the engines. In addition, renewed attention was given to the use of exhaust gases to raise steam in waste heat boilers which augmented the supply from the donkey boilers and reduced the overall fuel consumption of the auxiliary machinery.

After that time the power of heavy oil engines continued to increase steadily. In post-war years, however, the successful adaptation of a moderate degree of supercharging in two-stroke engines had provided 30 to 35 per cent. increase in power with m.i.p.'s of up to 130 lb. per sq. in. Engines are already under construction with single cylinder outputs of 1,650 b.h.p. and further increases to 2,200 b.h.p. are contemplated. Large slow-running engines therefore develop 10,000 to 17,000 b.h.p. and offer a serious challenge to the geared steam turbine for the propulsion of single-screw tankers and cargo ships. Without increase in the weight of the installaton, two medium-speed oil engines coupled through 2 : 1 reduction gearing to a single shaft have also been employed to develop these powers. The gearing is protected from engine-excited torque fluctuations by either fluid or, more recently, electromagnetic couplings installed between engines and pinions. Moreover, such arrangements show considerable advantages during manoeuvring. Although two-stroke engines are usually used for a propulsion unit of this type, highly supercharged four-stroke engines are also available when slightly lower powers are required.

Modern oil engines have excellent fuel consumptions of about 0·32 lb. oil per b.h.p.-hr. which correspond with overall efficiencies of 40 per cent. The most important feature of slow and medium-speed engines has been their recent conversion for burning boiler or residual grades of oil, however. The use of these fuels can provide a saving in fuel costs of up to 30 per cent. This achievement has given the oil engine a substantial lead over rival prime movers but the approach towards the theoretical efficiency leaves little scope for greater economy.

CYLINDRICAL OR WATER-TUBE BOILER

Before the 1914-18 war, water-tube boilers had superseded those of cylindrical types in warships and had proved superior in performance and operation. The working pressure of boilers in merchant ships advanced slowly during the first quarter of this century and the maximum employed was little in excess of 250 lb. per sq. in. Over this period the cylindrical boiler predominated throughout the whole power range of steam machinery. A considerable number of water-tube boilers were installed in merchant ships during the Great War, however, but their satisfactory service did little to dispel the prejudice against them except in America, where war-time construction comprised the major part of the merchant fleet. The development of economical steam-turbine machinery installation during the 1920's demanded H.P.-inlet conditions which could no longer be met by cylindrical boilers and the water-tube type now controlled the field of high-pressure and high-temperature steam production.

The benefits of advanced steam plants were soon evident by the appreciable reductions in specific fuel consumptions. The S.S. Duchess of Bedford, completed in 1928, was fitted with Yarrow boilers with a working pressure of 340 lb. per sq. in. at 670 deg. F. total temperature. The fuel consumption of the main machinery was recorded as 0·57 lb. per s.h.p.-hr. When compared with a Scotch boiler installation of eight years earlier a fuel saving of at least 15 per cent. was evident. Three years later the Empress of Britain entered service and her full power of 60,000 s.h.p. was developed by turbines supplied with steam at 425 lb. per sq. in. and 725 deg. F. On trials the same fuel consumption was recorded, but in this case it represented the all-purpose requirements. An appreciable advance in the use of higher steam conditions occurred in 1936 when construction commenced on the turbo-electric tanker J. W. Van Dyke. The two Babcock and Wilcox boilers of this ship were designed for a maximum working pressure of 675 lb. per sq. in., the superheater outlet steam being at 625 lb. per sq. in. and 835 deg. F. The fuel consumption of the main machinery was approximately 0·51 lb. per s.h.p.-hr. In the sister tanker Robert H. Colley, laid down in 1938, the steam temperature was raised to 910 deg. F., which was the most advanced condition used in merchant ships in the pre-war and early war years.

Some remarkable high-pressure installations were also completed, notably the 3,200 lb. per sq. in. of the Benson boilers in the Uckermark, 1,990 lb. per sq. in. by Loeffler type in the Conti Rosso and the Potsdam with 2,650 lb. per sq. in. working pressure. Such high pressures were rarer, however, and the main object has since been for pressures below 1,000 lb. per sq. in. with high degrees of superheat.

Water-tube boiler makers were active in their design advancement and by 1938 boiler efficiencies of 87 per cent. were possible. This was partly responsible for the low overall fuel consumptions of propulsion machinery. Of equal importance were the increases made in total heating surface and the rates of evaporation produced by single boilers for this permitted boiler plant of reduced size and weight. In addition, high quality fusion-welded joints replaced those of riveted type in the fabrication of boiler drums and by this means weight saving alone exceeded 1¼ tons per drum.

In America the Scotch boiler had practically died out by 1939, for a year later special arrangements had to be made to supply boilers of this type for 60 cargo ships ordered by Britain. In Britain, however, the cylindrical boiler has retained some of its popularity for both main and auxiliary steam generation, due to its rugged characteristics and it is usual practice to use water-tube boilers where steam pressures exceed 300 lb. per sq. in. Steam-turbine installations at present engine ships of 50,000 s.h.p. per screw or 200,000 total s.h.p. and as greater powers will not be required for some years, it is natural that research should be concerned with reducing fuel consumptions well below 0·5 lb. per s.h.p.-hr. and developing more compact plants. Economical units incorporating one or more reheat points are at present under consideration and it seems that gas-fired reheaters will supersede those of steam type. Increased steam conditions at the H.P.-turbine inlet still present a major source for improved economy. The tanker Atlantic Seaman, which has been in service for five years, has a turbine plant working with inlet steam at 600 lb. per sq. in. pressure and 1,020 deg. F. This machinery remains in advance of other merchant-ship installations and fabrication, design and service problems of high temperature materials are largely responsible for this position.

Of the ships at present under construction all in excess of 20,000 tons will employ geared steam turbines for main propulsion. Within the size range 100 to 20,000 tons, 70 per cent. will be propelled by oil engines, while the remainder, with isolated exceptions, will have steam reciprocating or turbine main machinery. Turbo or Diesel-electric transmission have not proved popular although restricted gear-cutting machine capacity increased the number of installations of these types during the last war. In some instances, however, turbo-electric main machinery has been preferred for large oil tankers in order that the main generator could be used to supply the cargo pumps when in port.

Both tankers and ore carriers have increased in size to meet the needs of supplying the expanding oil, chemical and metallurgical industries. Vessels of these types at present rival large passenger ships in size, but retain single-screw propulsion. To meet these conditions steam turbine manufacturers in particular have developed compact power plants developing up to 20,000 s.h.p. Further progress is continuing in this direction and double-reduction gearing in particular is the subject of extensive researches. The problems of successful transmission of gear-tooth loads of two and three times recognised pre-war levels have not yet been satisfactorily solved and surface hardened and ground gears are at present under consideration.

GAS TURBINES AND NUCLEAR REACTORS AS POWER SOURCES

In recent years other forms of prime mover have been considered for merchant ship propulsion, but so far these have not proved sufficiently attractive for general service.

The marine gas turbines at present under development for marine propulsion purposes are of open-cycle type. In general, the H.P. turbine drives an axial compressor as an independent unit while the L.P. provides the useful output and exhausts through a heat exchanger which preheats the inlet charge to the combustion chamber. The designs vary considerably, but can be considered in two main categories. The first covers those of lightweight construction, under 7 lb. per h.p. and developing up to 6,000 s.h.p. The H.P.-inlet temperatures of about 820 deg. C. limit the life of the hot parts to little more than 1,000 hours. Units of this type power light naval craft only, for a satisfactory life in excess of 20,000 hours is required for the main engines of merchant ships. This is at present obtained by limiting the top temperature to below 700 deg. C. in medium-weight plants of 25 to 30 lb. per s.h.p. Both classes of gas turbine have overall efficiencies of about 20 per cent., but when the long service reliability of the latter has been established, advances in top temperatures and design should provide fuel consumptions below 0·5 lb. per s.h.p.-hour. Since these engines cannot be run astern, either electric transmission, reversible-pitch propellers or reduction gearing with reverse trains must be used. Of these, the last quoted is receiving the greatest attention and is likely to predominate in future installations.

In France remarkable progress has been made recently in a power plant comprising a free piston gas generator and geared gas turbine. Turbine inlet conditions of four atmospheres pressure and less than 500 deg. C. are used as the peak temperature of the thermodynamic cycle occurs in the cylinder of the free piston gas generator. Overall thermal efficiencies therefore approach those of existing oil engines and are represented by a fuel consumption of 0·39 lb. Diesel oil per s.h.p.-hour. The problem of manoeuvring does not apply in this instance as astern wheels are incorporated in the turbine shaft.

The size of the gas generator has been standardised so that equal reliability may be obtained with all units. High-power plants will, therefore, comprise multiple units supplying one or more geared turbines. The first main marine installation of this type was installed in the 800-tons d.w. Cantenac, completed in 1954, and other ships at present under construction will be similarly fitted.

The construction of two submarines for the U.S. Navy in which the heat developed in a nuclear reactor is used to raise steam for supplying both main and auxiliary turbine machinery, has resulted in wide speculation of the possible adoption of similar power plants for merchant-ship applications. Indeed such an impressive statement that the fissioning of 1 lb. of uranium produces heat equivalent to 2,300 tons of coal or 300,000 gallons of oil, raises visions of revolutionary changes in the design of merchant ships and their machinery. As these changes would solve many existing problems, it seems that thermal reactors must eventually provide the energy for steamship propulsion. When this event will be possible depends on the rate of progress made in reducing to more attractive levels the weight, size and cost of reactors and screening and the satisfactory solution of control and maintenance problems. It appears that the power/weight ratios of these units will be better suited to the higher-powered plants of large cargo and passenger liners than to the many low-powered installations in smaller ships. Undoubtedly, the latter will continue to be engined with conventional prime movers.

In the submarine U.S.S. Nautilus, purified water under high pressure forms the primary coolant which extracts the heat from the thermal reactor. The steam then raised in heat exchangers is relatively low pressure and temperature, probably not more than 180 lb. per sq. in. and 440 deg. F.; consequently, geared steam-turbines of moderate thermal efficiency are used and high temperature is confined to the primary coolant section. In effect, the controlling factor is the rate at which heat can be extracted from the small volume of the thermal reactor and providing this is adequate to meet the demands, thermal efficiency is of only secondary importance. It is related to the size of plant, however, and for this reason fast reactors and liquid metal primary coolants may be superior for steamships.

An examination of the history of one particular field of engineering has indicated that the remarkable increases which have occurred in the prosperity of nations, during the last century and a half, can largely be attributed to the achievements of the engineer. It is also true that the countries which have encouraged engineers and industry enjoy the highest standard of living. To-day we aim to improve our living standard still further and, at the same time, assist other countries to do likewise. That the engineer is continuing to play his part is evidenced by the high rate of technical progress maintained during post-war years.

THE STUDY OF MODELS AS AN AID TO SHIP DESIGN*

EXPERIMENTAL DATA FOR MARINE DEVELOPMENT

By R. W. L. Gawn, C.B.E., D.SC., R.C.N.C., M.I.N.A.†

The following paper deals with the dominant part played by research on ship models in the development of the shape of the hull and propeller. In attaining the highest standards of performance, speed, endurance, seaworthiness, manoeuvring and freedom from vibration are all involved, and each of these factors will be considered.

WILLIAM FROUDE

The scientific approach has developed largely during the last century under the impetus of the invention of mechanical propulsion for ships. Prior to this the sailing ship had developed gradually over many centuries largely by craftsmanship. Sails had in turn replaced the oar which superseded after a long period the primitive log or dug-out propelled by the human hand.

It is not inappropriate for ship shape to be considered at a meeting of the British Association at Bristol because it was at a former meeting in the West Country, namely at Exeter, as long ago as 1869, that a committee presented their report, famous in naval architecture, on the stability, propulsion and sea-going qualities of ships.[1] The committee recommended experiments on ships to determine the resistance and rolling characteristics, emphasising that these were the aspects of naval science concerning which reliable information was most urgently needed. William Froude, a genius of Devon, was a member of this distinguished committee. He agreed with the desirability of trials on ships but doubted the accuracy of the results that would be achieved and was concerned at the time and expense involved. He considered that model experiments afforded a reliable solution and would be more fruitful of results. He was led to this view from tests he had carried out, the most important of which were in the River Dart with three different sizes of two parent models.[1] The historical models, known as "Raven" and "Swan," are illustrated in Fig. 1 and may now be seen in the Science Museum at South Kensington, London. The results were imperfect in some respects, but were considered by Froude reasonably to confirm the law of comparison bearing his name. Briefly, the resistance of a ship is determined from that of its model in proportion to the cube of the linear dimensions at corresponding speed. The latter is proportional to the square root of the linear dimensions. There was sharp criticism of his proposals as the few model experiments that had been carried out previously proved unsatisfactory and even contradictory. However, the Admiralty decided to give the idea a trial and in 1872, an experiment tank was completed at Torquay under Froude's direction and in accordance with his plans. The project proved an immediate triumph. Naval architecture was revolutionised and the foundations laid for a scientific basis of ship design.[2] Every maritime country of importance now follows this method, largely on the principles Froude laid down. As a grateful tribute to his genius by naval architects of many countries a memorial was unveiled in September, 1954, marking the site of the first experiment tank and commemorating Froude's outstanding contribution to the science of naval architecture. A volume[3] has also been prepared as part of the memorial containing the many papers published by Froude with an account of his life and work.

Froude's chief work was carried out for the Admiralty. The original establishment was of a temporary character and after 14 years was replaced by an experiment tank on the present site at the Admiralty Experiment Works, Haslar, where ship-model research has continued since 1887. A larger tank for tests at high speed was provided in 1932. Other laboratories have since been added to meet the complicated requirements of the modern Navy.[4]

* Paper entitled "Model Research and its Application to Ship Design" read before Section G of the British Association at Bristol on Friday, September 2, 1955.

† Superintendent, Admiralty Experiment Works, Haslar.

EXPERIMENT TANKS

The chief feature of an experiment tank is a long covered waterway in which models are tested to ascertain their resistance. The models are towed from a precision dynamometer mounted on an experiment carriage driven at prescribed speeds. Apparatus is also provided on the carriage for propeller and other investigations. The ship models are seldom longer than about 20 ft. and are generally made of hard paraffin wax in the form of a shell upwards of about 1 in. thick when finished but less for small models. They are accurately shaped to guidance grooves cut in the wax by a special machine.

The larger tank at Haslar is illustrated in Fig. 2. The waterway is 890 ft. long, 40 ft. wide and 18 ft. deep generally. The experiment carriage is of steel girder construction driven up to a maximum speed of 40 ft. per second. Uniformity of speed is an essential requirement and this is maintained within a tolerance of 0·25 per cent. To-day, a few shipbuilding firms in Great Britain have similar equipment although different in details and of smaller size. In addition there are two experiment tanks at the National Physical Laboratory, Teddington, which are also used by shipbuilding firms, and extensions are in progress. Comparable facilities are provided in other countries and there are now upwards of 50 experiment tanks in the world.

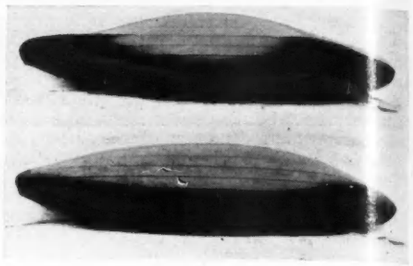


Fig. 1 William Froude's original models ; above "Raven," below "Swan." They helped to confirm Froude's law of comparison which enabled ship behaviour to be predicted from model tests.

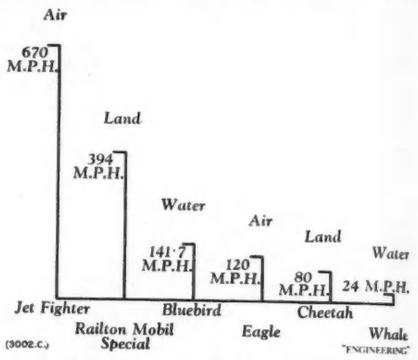


Fig. 3 Maximum speeds of living creatures and record speeds up to January, 1949, of land, sea and air transport. High speeds are clearly more difficult to attain in water than in air.

HULL RESISTANCE

In contrast with other forms of mechanical transport a ship has to float and to move through water. The resistance to motion is much greater than in air for comparable sizes and speeds. This is reflected both in the speed of living

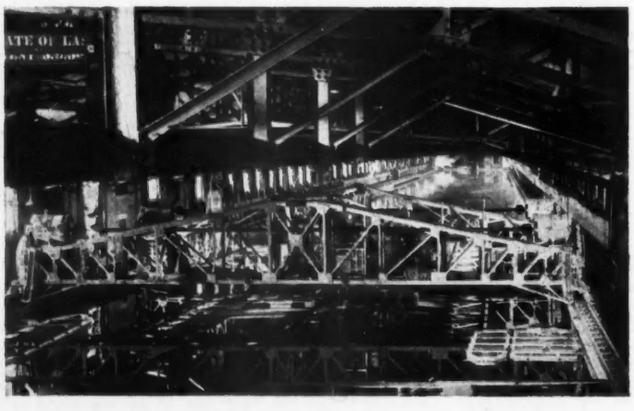


Fig. 2 The larger ship tank at the Admiralty Experiment Works, Haslar. Models, generally made of paraffin wax, are towed along the tank from a dynamometer mounted on a carriage which can be driven at various speeds. The waterway is 890 ft. long, 40 ft. wide and 18 ft. deep.

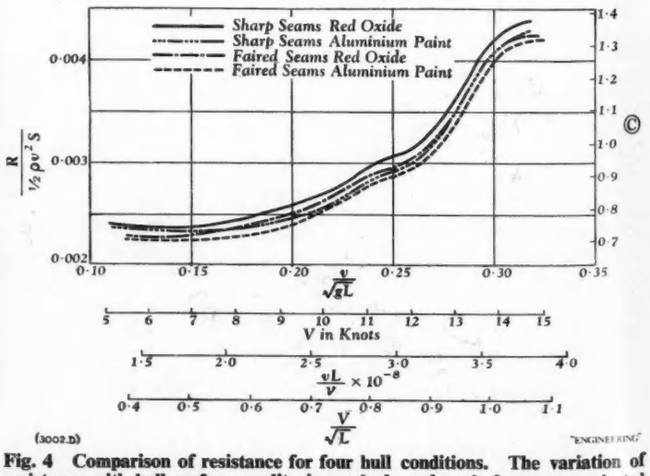


Fig. 4 Comparison of resistance for four hull conditions. The variation of resistance with hull surface quality is marked, and such features as riveted or welded construction may also considerably affect ship speed.

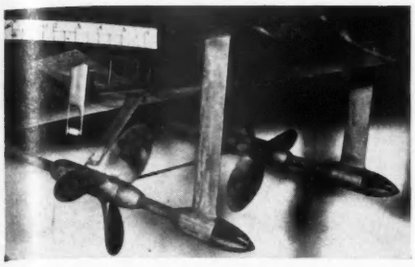


Fig. 5 Shaft-bracket flow indicators. By aligning external features to the direction of local water flow resistance can be minimised.

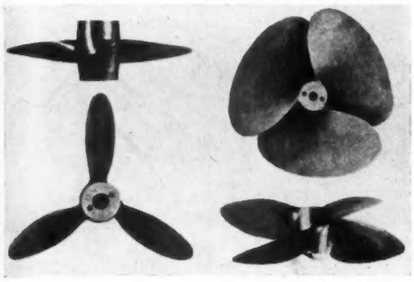


Fig. 7 Narrow and wide propellers, blade-area ratios 0·2 and 1·1. The skin-friction resistance is greater with a wide blade but there is less tendency towards cavitation.

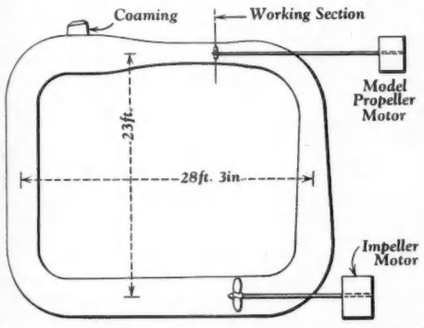


Fig. 8 Water tunnel in which the pressure can be varied to simulate sea conditions for cavitation testing of propeller models.

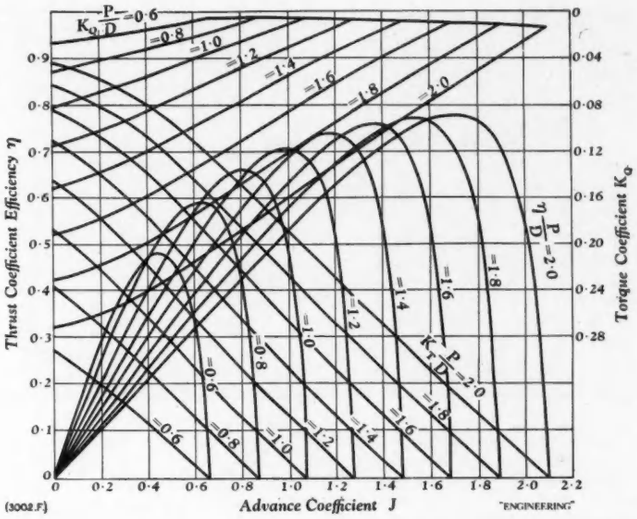


Fig. 6 Effect of pitch on propeller performance, with 0·8 blade-area ratio. The results are given for one specific blade width only.

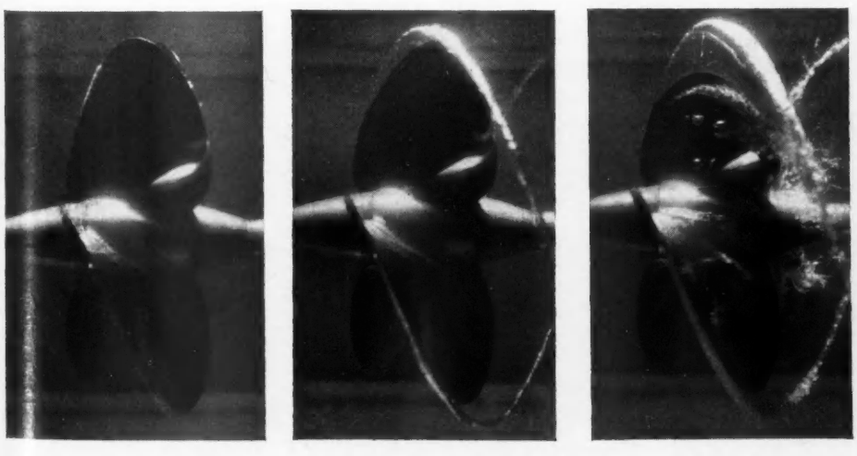
creatures and the much greater speed of mechanical transport,[5] as illustrated in Fig. 3. The first three illustrations in Fig. 3 relate to authentic record speeds of aircraft, car and boat, respectively, to date January, 1949. The remaining three relate to maximum speeds that have been quoted for bird, land animal and marine animal, respectively.

A large proportion of the resistance of a ship is due to viscosity and is known as skin-friction resistance. Other sources of resistance are the energy absorbed in generating surface waves and that dissipated in eddies shed from any more or less abrupt change in shape of the hull or appendages. The excess of the total water resistance above the skin friction is termed residuary resistance. The action of the air on the hull above the water level also promotes resistance, which, although quite small on a calm day, becomes important when the ship proceeds into a strong wind. A difficulty in predicting the resistance of a ship from the results of tests of a geometrically-similar model is that skin friction depends on viscosity and the residuary resistance on gravity. The former is governed by Reynolds' law and the latter by Froude's law. Froude measured the skin-friction resistance of a series of planks of various lengths up to 50 ft. He applied the results to estimate the skin friction of a model hull and derived the residuary resistance by subtraction from the measured resistance of the model. The plank results were extrapolated by him to predict the skin friction of a ship. The total ship resistance was then obtained by adding the residuary resistance deduced from the model experiment.

RIVETED AND WELDED HULLS

This empirical procedure bristles with difficulties in practice although long and successful experience has established firm confidence in the method. Froude in his famous towing trial of the Greyhound[6] achieved fair success in correlating the resistance of the ship and model, although the results were not completely satisfactory. Recently the British Shipbuilding Research Association have completed trials on a small ship named Lucy Ashton.[7] Propulsion was by air jets to overcome the objections of a towing trial such as the difficulty of reliably measuring the tow-line pull and avoiding interference from the towing vessel. The jet thrust was accurately measured and the ship resistance correctly established within fine limits. The main purpose was to check the predictions from a series of models of the ship of different sizes, and the upshot was to endorse the procedure in principle and very largely in magnitude at higher speeds but not completely so at all speeds. This may be a reflection on the basic skin-friction data. The latter has received much attention for many years, but so far no alternative to the Froude coefficients has commanded general acceptance although it is agreed that a skin-friction formulation in line with modern concepts of physics is essential.

A further difficulty is that the resistance depends on the condition of the hull surface. This has long been recognised but the Lucy Ashton trials afforded firm evidence, see Fig. 4. The skin-friction resistance with exposed plate edges and butts as in a riveted ship was found to be 5 per cent. greater than with the edges faired to simulate to some extent a welded ship. Moreover, when the ship was coated with a very smooth aluminium paint in lieu of red-oxide paint, the resistance was reduced by a further 5 per cent. The advantage of a smooth hull is also brought home by the evidence gradually being accumulated from the results of trials of modern ships of welded construction. Hughes[8] also suggests that advance is possible if the hull surface could be well bonded with plastic. The problem is much more complex than the production of a smooth surface. Precautions must be taken to avoid corrosion of the steel hull due to chemical and galvanic action which can be severe in sea water. Moreover the hull soon becomes coated with marine growth. The nature of the growth depends on the conditions of service of the ship, but as a broad average it has been deduced that the skin-friction resistance due to fouling increases at the approximate rate of one-eighth per cent. per day. This is large since it means, for example, that the friction resistance will be increased by about 25 per cent. when the ship is six months out of dock and 50 per cent. after a



Corresponding ship speed 13·9 knots | Corresponding ship speed 29·8 knots | Corresponding ship speed 44·9 knots

Fig. 9 Cavitation at working slip, showing a model of a destroyer propeller under test. Cavitation increases with speed, and leads to such troubles as pitting and loss of torque.

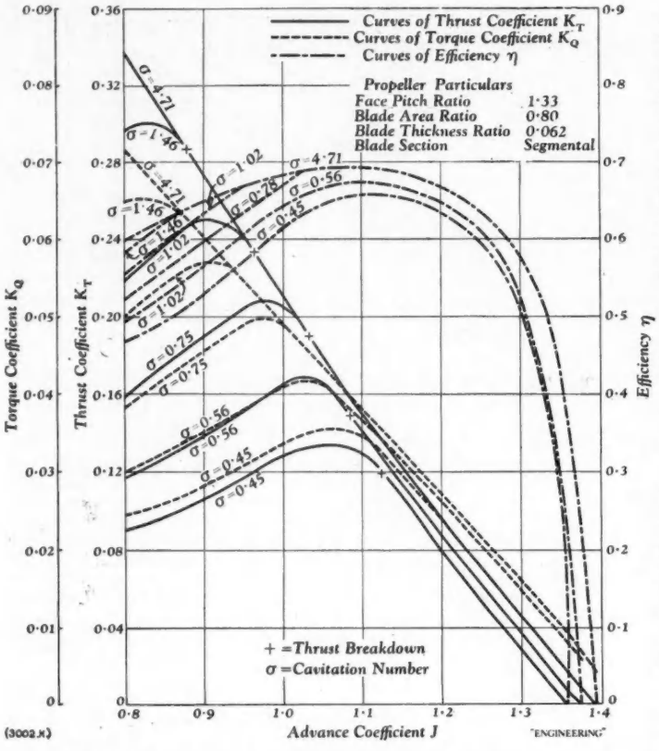


Fig. 10 Cavitation tests of a model propeller. Thrust and torque, and to a lesser extent efficiency are reduced by cavitation.

year. A few decades ago the average increase was about double that quoted, which speaks for itself regarding the advance that has been inspired by ship-model research.

BROAD AND NARROW SHIPS

Model experiments indicate that skin friction accounts for as much as about 80 per cent. of the total resistance of many merchant ships and about 50 per cent. for fast warships and liners. If the ship is long and narrow, the skin-friction resistance increases owing to the greater wetted surface of the hull, and the residuary resistance is comparatively small. On the other hand, if the ship is short and full, the wetted area, and therefore the skin-friction resistance, is reduced, but the residuary resistance will be large at higher speeds, at which wavemaking is important. A broad ship may well have less resistance than a narrow ship and this early discovery from ship-model research led to an increase in safety of ships. The optimum proportions and shape have been clarified by model experiments but in deciding on the shape of a specific design, compromise must frequently be accepted. To quote one example, a warship must be propelled economically at cruising speed in the interests of greater endurance, as well as to obtain the highest possible speed. Requirements of hull shape for cruising and full speed are often conflicting, and the relative importance attached to each influences the design. One instance is the broad flat knuckle stern now embodied in many classes of warship. This was formerly prejudicial to cruising speed, but as a result of model research, a favourable size and shape has been evolved with rounded knuckles to effect a gain at cruising speed as well as at full power.

A considerable amount of research has been devoted to the determination of the resistance of a methodical series of model hulls systematically varied in proportions and shape. The results of the first series of such tests were published by Froude[9] as long ago as 1878. One of the latest was published last year.[10] The range is wide, from a lean destroyer with a block coefficient of about 0·5 to a full tanker with a block coefficient of about 0·8 or more. Length, beam, draught, displacement, position of centre of buoyancy and details of shape of the waterlines and hull sections each receive concentrated attention. The basic information obtained is invaluable to the designer in deciding on the shape of the hull, but even so it is necessary to arrange for tests of the model of the specific ship to obtain the utmost efficiency. Attention is also given to such items as hull appendages, bilge keels, rudders, the supports to the propeller shafts, docking keels and the circulating-water inlets and outlets of the condenser system of the machinery. All these appendages are sources of resistance which must be minimised. This is achieved if the feature is aligned to the local direction of flow of the water. Fig. 5 indicates the arrangement for determining the flow direction for shaft-bracket arms as an example. The angle taken up by the small vanes representing the arms is accurately recorded electrically inside the model hull, and the arms on the ship are arranged accordingly.

PROPELLER EXPERIMENTS

Propulsion of most ships is effected by one or more screw propellers located towards the stern. The propulsive thrust is equal to the rate of change of momentum imparted by the propellers to the water. Energy is dissipated in the race but this is minimised if the propeller is large since the imparted velocity and therefore the kinetic energy is reduced. The diameter of the propeller and the speed of rotation in conjunction with the speed of advance of the ship determines the race velocity and this has a major influence on the efficiency. Consequently the aim is generally to fit as large a propeller as practicable consistent with adequate clearance from hull and keel.

An approximation to the characteristics of the propeller can be obtained from theory, but the problem is too complicated for full reliance to be placed on this, and the marine-propeller designer turns to experiments for firm guidance. Many tests have been made on systematic variations of pitch, blade area, blade thickness, shape of blade section and shape of blade outline, and results, such as those in Fig. 6, are obtained.[11] This particular example indicates the effect of variation of pitch only for one specific blade width. The reference quoted includes results for a range of blade width. Fig. 7 illustrates the narrowest and the widest propellers, re-

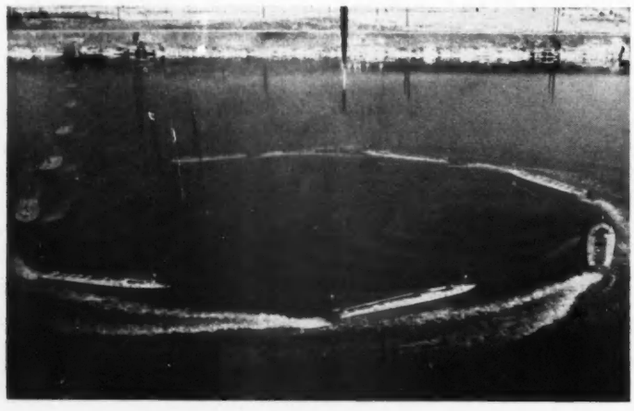


Fig. 13 Photographic record of turning path. In vessels which may be subject to bombing or torpedo attack a capacity to turn sharply is of special importance.

Fig. 11 Cavitation of a ship propeller.

Fig. 12 Propeller erosion induced by cavitation.

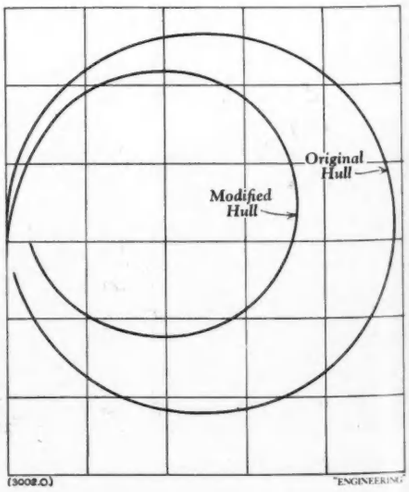


Fig. 14 Improvement of turning path achieved by modifying hull at the stern.

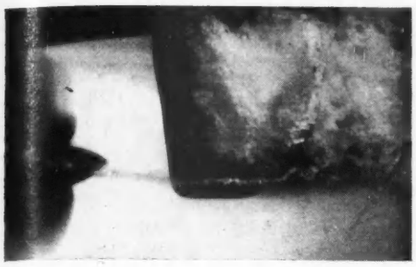


Fig. 15 Aeration of rudder on a model hull. This effect, known as "burbling," reduces rudder efficiency.

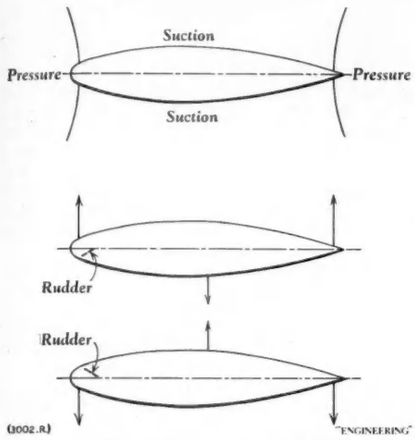


Fig. 17 When two ships are travelling close abeam there is a tendency for them to be drawn together more at the stern than the bow; to avoid collision the rudders must be set as shown.

spectively, of this series. If the blades of a propeller are wide, then power is wasted in overcoming the skin-friction resistance but the marine-propeller designer, unlike his aeronautical counterpart, must arrange sufficient width to avoid loss of efficiency due to cavitation. This is a phenomenon of vacuous cavities or bubbles in the water around the propeller, arising from low pressure. The cavities multiply with speed and eventually result in loss of thrust and torque and also of propeller efficiency. Our understanding of this pitfall has been greatly advanced by research in water tunnels, the pressure in which can be controlled to simulate that obtaining on the ship propeller. This type of model research is receiving increasing attention and there are now three propeller tunnels in Great Britain and some abroad.

Fig. 8 illustrates the tunnel at the Admiralty Experiment Works, Haslar. The growth of cavitation with speed on a model of a propeller for a destroyer is indicated in Fig. 9, and the corresponding propulsion characteristics in Fig. 10.[12] Thrust and torque, and to a less extent efficiency, are reduced by cavitation, although in this particular case there is no loss of efficiency until a speed of about 30 knots is reached. Such research leads to the development of the best design of propeller for a specific ship, to suppress or reduce cavitation. Fig. 11 confirms that the cavitation patterns of a ship propeller at sea are comparable with those of the model propeller but investigation has brought out differences in detail which are the subject of research. Broadly, cavitation is more severe on the ship propeller. Erosion of the propeller material is induced by cavitation, and this is also investigated by research in the tunnel. The need for this is evident from Fig. 12, which shows one rather severe case of an older propeller.

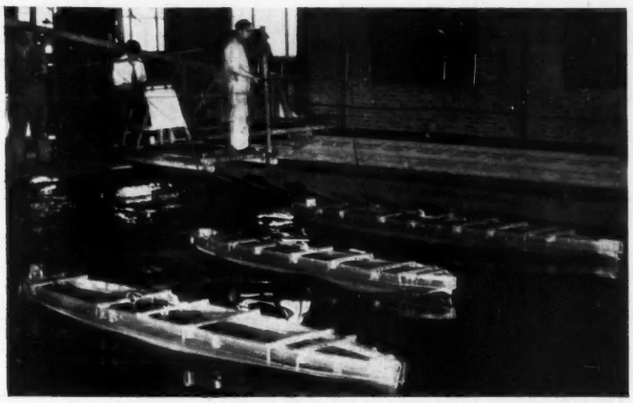


Fig. 16 Model tests of replenishment at sea. Ships proceeding close abeam at high speed are subject to mutual effects which complicate such operations as ocean refuelling. The method of manoeuvring is indicated in Fig. 17.

ELIMINATING VIBRATION

Much of the vibration in ships is excited by the propeller and it is necessary to minimise this to ensure efficient operation of such items as radar and fire-control instruments. The provision of adequate clearance between the propeller tips and the hull is one important requirement which has long received attention. Dependent on the frequency of vibration of the hull and of the propeller-shaft system, a ready way of avoiding vibration is to fit propellers with four or even five blades instead of three. Special care is necessary to limit cavitation owing to the increase of the number of pressure changes per revolution and in some cases overlap of one blade on another. Research in tunnels has avoided this drawback of multi-bladed propellers.

The hull significantly modifies the flow of water to the propeller and the action of the latter in turn augments the resistance of the hull. Accurate information on the mutual effects is essential for efficient design of both the hull and propeller. This is investigated by experiments on propelled models in an experiment tank. This mutual action can lead to greater cavitation and in order to investigate this and other aspects, a much larger tunnel is being provided. Research has shown that cavitation leads to noise and this is objectionable since in wartime the ship can be detected through the enemy's hydrophone and the source of noise attracts homing weapons. Propeller design has been modified as a result of research to reduce the consequential menace of noise.

MANOEUVRING

Ships must be able to change speed and direction and this is achieved through the action of the propeller and rudder but the shape of the hull, particularly at the stern, is also important. Manoeuvring qualities have long been investigated by model experiment and Admiralty interest has been intensified by the emphasis from war experience on the necessity of quick steering, quick manoeuvring and quick acceleration for hunting and attacking submarines. Avoidance of torpedo and bombing attack has also brought home the importance of quick turning. The speed and path when turning are determined photographically, the arrangements for test of a large model in an artificial lake being illustrated in Fig. 13.[4] An example of the lessons to be learnt is afforded by Fig. 14. The improvement in this design was obtained largely by alteration to the hull at the stern. Formerly destroyers turned in a large path at high speed; the size of the path varied indiscriminately to some extent between port and starboard. This has been shown by model research to be due to a breakdown in pressure on the rudder known as "burbling" associated with large aeration of the rudder as in the underwater photograph of a model, Fig. 15. This has been avoided by careful attention to rudder design. One consequence of turning is the outward heel of the ship under the action of the centrifugal force. If the turning is quick the angle will be increased and this could be a source of danger in severe weather. Research has established that quick

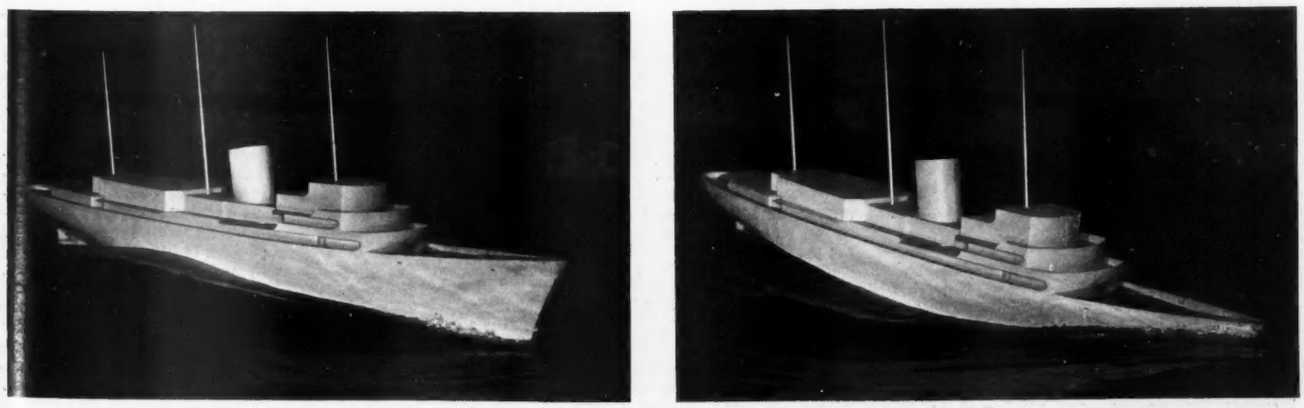


Fig. 18 Model of H.M. Yacht Britannia in waves. The model is undergoing pitching tests to determine the stability and seaworthiness of the full-size ship.

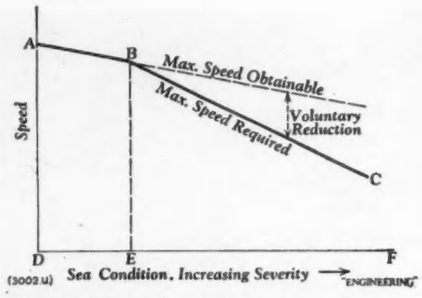


Fig. 19 Sustained speed at sea. In heavy weather speed must be reduced to minimise ship motion and prevent structural damage.

turning can be achieved without a large heel. It is important that the ship should be able to maintain a steady course as well as turn quickly. The mutual requirements of hull shape were at one time regarded as opposed but this was investigated, including the measurement of the forces and moments on the hull and rudder, to achieve a design which maintains course and can at the same time turn quickly. The determination of the rudder forces is also invaluable as a guide to the designer as to the structural strength and stiffness of the rudder and rudder stock and the power of the steering gear to operate the rudder.

Fig. 16[4] is of interest in showing the use of models for determining the manoeuvring requirements of ships when proceeding at high speed and close abeam for replenishment operations at sea. The tendency is for the ships to be drawn together more so at the stern than at the bow and as a result the rudders must be set with the after ends converging as in Fig. 17. This is contrary to the natural reaction of moving the rudder outboard to turn the ships away. The requisite rudder angle must be adjusted and maintained

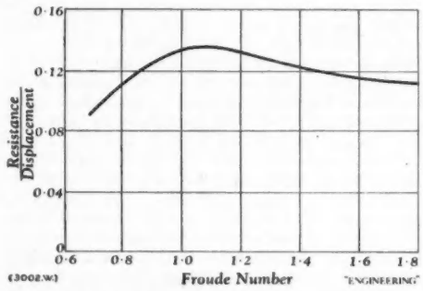


Fig. 21 Hull resistance at high speed. When a ship of appropriate design travels at sufficient speed to rise in the water, its hull resistance is reduced.

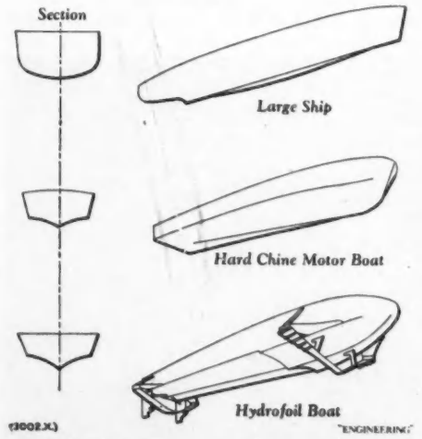
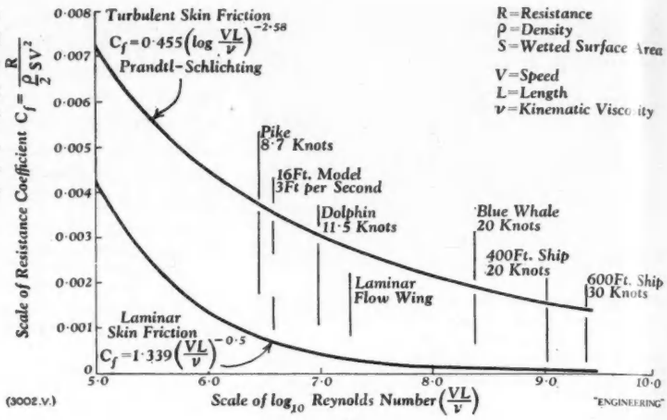


Fig. 22 Hull designs can be adopted to take best advantage of the effect indicated in Fig. 21.

Fig. 20 Skin-friction resistance. If hull surface could be made so smooth that flow became laminar instead of turbulent, skin-friction resistance would be very small.



with some precision to avoid the serious hazard of collision in this operation.

SEAWORTHINESS

A ship in rough weather is liable to oscillate violently. The motion is complicated and complete treatment has so far defied mathematicians, although knowledge has been advanced by considering the separate components. There are three rotary motions, namely roll, pitch, and yaw, about a longitudinal, transverse, and vertical axis respectively. Similarly there are three translational motions, namely surge, sheer, and heave, in the longitudinal, transverse, and vertical directions respectively. Roll, pitch, and heave are probably more objectionable and have been subject to most investigation, but the other components are far from insignificant.

Rolling has long received attention from the model experimenter. One of the early results was to clarify the great advantage of small bilge keels in limiting the oscillation. The size, position and shape are determined from tests on a model hull. The shape of the hull itself also plays a part in this, since the effect of the bilge keels is greatly enhanced by induced forces on the hull. Active reduction of roll, and to a marked degree, is effected by the Denny-Brown stabiliser, and research, both on a model hull in an experiment tank and on the stabilising fins in a cavitation tunnel, has ensured the utmost efficiency of this device.[13, 14] Sustained speed and steadiness at sea are paramount for warships. To quote one problem, the vertical movement of the flight deck of an aircraft carrier must be minimised in order that aircraft may operate in rough weather. If seas are shipped over the flight deck forward the aircraft will be unable to take off. Full attention is therefore given to the provision of adequate freeboard, the shaping of the hull forward and the avoidance of discontinuities of the side sponsons which are sources of heavy spray. Aircraft land on the deck aft and one aim is to obtain a favourable phase combination of pitch and heave so that the motion in the area of landing is as small as possible. Fans are also brought into play to simulate the effect of wind for information as to means of avoiding spray being blown inboard. Models of the above-water portions of a ship are tested in a wind tunnel and modifications embodied to avoid objectionable draughts in exposed positions. An account of one investigation on this in relation to H.M. Yacht Britannia[15] gives some indication of the attention paid to improving seaworthiness and airflow. Fig. 18 shows views of the model pitching to illustrate the procedure.

EXPERIMENT: A BASIS FOR THE FUTURE

Ships of to-day and yesterday owe their performance to investigations on models. What of tomorrow? Ships must continue to be stably supported, propelled and controlled. Waves will still be generated and water will cavitate. Experience shows that the problems are complex and extensive. Research in one field has emphasised the need for investigations of other aspects. The wide scope calls for co-operation in problems of common interest and some of these are considered by an organisation now known as the International Towing Tank Conference. Research, co-operative and otherwise, is recommended to co-ordinate procedure, predictions and nomenclature.[16]

Understanding of the fundamental physics has always been sought in ship-model research and the mathematician can point proudly to some elegant solutions which are being continually refined including the theory of wave resistance, propellers, ship motion, manoeuvring and boundary layer. However, close accuracy is essential for ships, and there is so far no indication that calculation can replace experiment although established theory has proved an invaluable guide.

Emphasis is veering towards the development of the best hull shape for seagoing conditions rather than for calm water, as formerly. Naval interest is evident from the manoeuvring tank now being constructed at the Admiralty Experiment Works, Haslar. Waves of mixed components are to be generated to provide for a realistic investigation of seaworthiness with coupled motions. Seas on the quarter and off the bow, which are the most objectionable, can be investigated. The three-dimensional freedom of submarines presents an involved problem owing to the urge for high speed. Stability derivatives must be determined and this involves tests of a model on a rotating arm. Provision is made for this in the manoeuvring tank. Moreover, the wide rectangular waterway is invaluable for free manoeuvring of ship models. This new conception and the large cavitation tunnel previously mentioned promise to be valuable additions to research facilities.

The boundaries of research are being thus further extended to meet the high operational standards demanded of the modern navy in this age of aircraft, guided missiles, nuclear weapons and radar, to mention only a few developments which have complicated warship design. Analogous considerations with different emphasis apply to the commercial ship in this highly competitive world. The author's account has mentioned some of the Admiralty work with which he is directly concerned but the reader may care to consult papers by Smith[17], Todd[18] and Van Lammeren[19] concerning other activities. We can look forward, as a result, to steadier, handier, faster and more economical ships. It is axiomatic that one quality of a ship must not be improved to an extent that another equally important quality is unduly sacrificed. One example only will be quoted, namely speed, the price of which is high in all mechanical transport and especially for ships. True about 150 knots has already been reached and higher speeds are within grasp but only for very small craft with no useful carrying capacity and no ability to operate in other than calm water. A speed of 30 to 35 knots is the present limit for large ships and about 40 knots for intermediate

or small vessels. Speed is reduced in rough weather. Fig. 19 is of interest in this respect. Maximum speed in moderate seas is indicated by AB but speed is voluntarily eased in heavy weather to BC to reduce ship motion and prevent structural damage. The aim of research is to ensure a higher limit both for BC and for AB. This neat statement of the problem was suggested by one of the delegates to the 1954 International Towing Tank Conference.

LAMINAR FLOW FOR SHIPS

Smoother hulls can be looked forward to with an attractive reduction in skin-friction resistance, although progress will be largely determined by shipyard practice and economics. Alluring, if imaginative, possibilities arise if the hull surface could be made so smooth that the flow regime became laminar instead of turbulent as at present. It is evident from Fig. 20 that the skin-friction resistance of a ship would then be extremely small. It would be necessary to devise means to avoid imperfections due to marine growth, corrosion or damage. All service openings in the hull must be arranged aft, otherwise turbulence would be stimulated. If these idealistic requirements were realised economy of propulsion at cruising speed would be revolutionised. The maximum speed of a submerged submarine would be appreciably increased but that of a floating ship would be limited by the rapid growth of resistance due to the generation of waves. For example, the speed of a destroyer might be increased by about five knots. The shape would doubtless be modified and the length increased to reap the full benefit of the perfectly smooth hull but the increase of speed would be a few rather than many knots. If a sufficiently high speed could be obtained the ship would rise in the water and the resistance decline as in Fig. 21. This action is amplified by a planing hull or hydrofoil, illustrated in Fig. 22. So far this principle has only been applied to comparatively small craft with a correspondingly low hump speed. Abnormally powerful and compact machinery would be needed for a large ship to bridge the hump speed which would be rather high, say about 70 knots. Much stronger and stiffer structural material would also be necessary to resist pounding in a seaway. The lesson, in the author's view, is that those interested in attaining speeds much exceeding say 50 to 60 knots should look to aircraft with light loads and balance the method of transport against heavy loads carried in a large ship at smaller speed.

Summing up we may look forward to faster, steadier, handier and more economical ships. As in the past, advance will be circumscribed by, among other factors, the physical limits imposed by the density and viscosity of water and of air and the vapour tension, air content and surface tension of water. It has been shown above that density is a real barrier to fast speed. This may also be appreciated from the imaginative statement that if a 600-knot aircraft could plunge into water and continue submerged then the speed would be reduced to about 60 knots. In reality it would be necessary to stiffen the structure and provide watertight integrity and the speed would fall far short of 60 knots.

SHIP TANKS AND WIND TUNNELS

Much of interest has been unavoidably omitted but it is hoped that sufficient has been included to indicate the wonderful achievement of ship-model research. The pioneer investigations placed naval architecture on a firm foundation and enabled the best use to be made of developments in propelling machinery. They also played an important part in encouraging interest in fluid flow and kindred problems. It is reasonable to speculate that the remarkable benefits derived from experiments on ship models stimulated investigations on models of aircraft in a wind tunnel in the early days of flying, the consequences of which are so manifest in the advance of aeronautics and other branches of applied science. In addition to ship research use is made of the facilities to investigate other items, examples being hydrodynamic aspects of underwater weapons and anchors. There is scarcely a volume of the *Transactions of the Institution of Naval Architects* and similar societies which does not contain some account of ship-model research; truly a wonderful harvest from the original seed.

Acknowledgments.—Full use has been made of published information in preparing this brief outline and grateful acknowledgment is made to the Institution of Naval Architects and the North East Coast Institution of Engineers and Shipbuilders, for permission to reproduce the relevant diagrams mentioned in the references. The paper is published with the approval of the Admiralty, but the responsibility for any statement of fact or opinion expressed rests solely with the author.

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CABLE SHEATHING PROTECTION

November Symposium at I.E.E.

A symposium on "The Protection of Cable Sheathing Against Corrosion" has been arranged by the Corrosion Group of the Society of Chemical Industry, and will be held at the Institution of Electrical Engineers, Savoy-place, Victoria-embankment, London, W.C.2, on Friday, November 18.

Papers to be read will include "The 'Phenol Corrosion' of Lead," by Mr. R. L. Davies and Mr. E. L. Coles, British Insulated Callender's Cables, Limited; "Cathodic Protection of Telecommunications Cables," by Mr. J. Gerrard and Mr. J. R. Walters, Post Office; "Protection of Buried Power Cables," by Mr. J. H. Gosden, Central Electricity Authority; "The Behaviour of Aluminium-Sheathed Cables," by Mr. P. A. Raine, Johnson and Phillips Limited; and "The Mechanism of Corrosion of Metal Pipes in Soils and Practical Methods of Prevention," by Mr. W. W. Robson and Mr. A. R. Taylor, Associated Lead Manufacturers Limited.

Further particulars of the symposium and forms of application may be obtained from the secretary of the Society, 56 Victoria-street, London, S.W.1. The honorary secretary of the Corrosion Group of the Society is Mr. S. C. Britton, Tin Research Institute, Fraser-road Greenford, Middlesex.

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ELECTRICAL ACCIDENTS IN MINES

At the end of June, 1952, there were 105,157 electric motors in use at mines coming under the Coal Mines Act, 1911; their combined horsepower was 3,326,539. The corresponding totals for 1951 were 97,183 and 3,184,630. These figures are given in the 1952* report of H.M. Principal Electrical Inspector of Mines which has just been issued. In view of the extensive programme of mechanisation being carried out by the National Coal Board, it is probable that the rate of increase in the use of electricity has grown in more recent years.

The report does not contain any explanation for its late appearance, but although more recent information would be of interest and value it serves its purpose in forming its contribution to a record which has been built up over many years.

In view of the work of the Safety in Mines Research Establishment, of the Mines Inspectorate and of the manufacturers of electrical apparatus it might be expected that the accident rate would show a gradual improvement over the years. The record does not directly indicate this; there were five fatal accidents due to shock or burns in 1952 as against an average of 2·9 for the previous nine years and 60 cases of injury compared with an average of 55. In view of the great extension in the use of electricity in mines, it is possible that these figures do actually indicate an improvement in view of the increasing opportunities for accidents. A proper assessment of the situation would, however, require statistics about the number of men exposed to the possibility of accident. The report does not give any information on this matter. The record of fatal electrical accidents was slightly more favourable than is indicated by the figure 5 as one of the deaths was caused by the falling of a heavy cable owing to the breaking of the canvas suspenders. As it was an electric cable, the accident was recorded as electrical; actually it was mechanical. In addition to the 65 accidents involving shock or burns, there were 11 cases of injury due to the ignition of firedamp or coal dust; the average for the previous nine years was 8·6. There were no fatal accidents due to this cause in 1952, the average for the previous nine years being 4·3.

As is all too common in reports dealing with factory or mine accidents, an unduly large proportion, fatal or otherwise, were sustained by skilled men. Four out of five of the deaths due to shock were of electricians. Particulars given show that the majority of accidents to skilled workers are due to over-confidence or oversight. The predominant influence of human frailty in building up the accident record is shown by a table in the report which covers both accidents and "dangerous occurrences." Of a total of 95, no less than 78 were attributed to "installation or maintenance," or to "misuse, negligence or ignorance." The reliability of present-day electrical plant is indicated by the fact that only nine occurrences are attributed to "design or unsuitability of apparatus."

* *Report of H.M. Principal Electrical Inspector of Mines for the Year* 1952. H.M. Stationery Office. (2*s.* net.)

LINEAR ACCELERATION OF CHARGED PARTICLES TO HIGH ENERGIES*

DIRECT AND INDIRECT ACCELERATORS

By C. W. Miller, M.SC., F.INST.P.†

Summary.—The paper gives a general account of the development of linear accelerators during the past 25 years. The work of Cockcroft and Walton is taken as a suitable starting point and distinction is made between direct and indirect acceleration. Several post-war accelerators are briefly described and their performance given. Distinction is made between equipments for protons and for electrons and further subdivision made of the various types of electron accelerator. Some of the engineering problems are mentioned and possible applications briefly reviewed.

INTRODUCTION

A theorem in elementary electricity states that when a particle of charge e moves under the influence of the electric field between two electrodes between which there is a potential difference of V it acquires an energy eV. This energy appears as kinetic energy and since the velocity of atomic particles may well approach the velocity of light c the energy-velocity relationship must be specified on a relativistic basis. This can be done as follows:

$$\text{Energy } E = eV = (m - m_0)\,c^2$$

and

$$\frac{m}{m_0} = \frac{1}{\sqrt{(1-\beta^2)}} = 1 + \frac{eV}{m_0 c^2}.$$

where β is the ratio of the velocity of the particle v to the velocity of light, m_0 is the rest mass of the particle and m is the mass at velocity v. These relationships account for some difference in technique in the acceleration of different types of particles since differences in rest mass cause differences of large order in the energies at which velocity can be considered as near to that of light. Energy of a particle is usually expressed in units of the electron volt eV, i.e., the energy acquired when a particle of one electronic charge is accelerated through a potential difference of one volt. This is often an inconveniently small unit and the multiples keV and MeV (10^3 and 10^6 eV) are used. For 10^9 eV two units are at present current, GeV in Europe and BeV in America.

The acceleration of electrons in straight lines by the potential difference between two electrodes has, of course, been known in the form of small X-ray tubes for a considerable time. When, therefore, the need for high energy particles for atomic research was first felt this simple process was first investigated. As a starting point for the present report the work of Cockcroft and Walton (*c.* 1930) will be considered and we shall examine progress from that time confining our attention to devices in which the particle always moves in a straight line. (Other devices in which at least some part of the path of the particle is curved have found much use but these are considered in a paper by J. B. Adams.) It should be noted that in the method of acceleration mentioned so far the accelerating potential has to be generated in full and the accelerating structure has to withstand the full potential difference. Such devices may therefore be termed direct linear accelerators. It is perhaps obvious that insulation problems set an upper limit of energy for direct accelerators and methods of avoiding the difficulty have had to be found. Using such methods particle energies corresponding to large potential difference are acquired although only relatively small potential differences are applied to the apparatus. Such arrangements may be classified as indirect accelerators. In the 25 years of development many types of particle accelerator have been built and energies have ranged from the modest beginnings of some tens of keV almost up to the GeV range while the particles accelerated have included electrons, protons and various ions. For physical research the number of particles accelerated, i.e., the current output of the equipment, has often been of little concern, the major interest being in the energy developed. With present developments in meson physics and the comparative rarity of wanted events current output does become of interest in high-energy machines. Further, as will be shown, there are applications of accelerators in more mundane fields and for these power output and indeed efficiency are a vital concern.

It is not possible in a single paper to deal in any adequate degree with the fundamental theory of the various types of accelerator. It is intended rather to give a general review of development in an already wide field. To this end Fig. 1 gives a genealogical plan of the development of linear accelerators, and it should be immediately admitted that this has been drawn up to show general trends in development rather than to include all work on the subject.

DIRECT ACCELERATORS

When in the late 1920's interest in atomic physics turned to the bombardment of elements with energetic particles the sources of such particles were the then known radioactive materials. It soon became clear that high-speed particles were required in quantity greater than could be obtained from such sources. At this time there was already a background of high-voltage engineering experience and X-ray tubes operating at, for the time, relatively high voltages were well known. Against this background and in the light of high-voltage experiments by such workers as Lauritsen and Bennett[1] and Allibone[2], it was clearly a correct procedure for Cockcroft and Walton to apply and extend such techniques. Their first equipment[3], which was a conventional half-wave rectifier circuit using two rectifiers in series, generated 300 kV, this voltage being applied directly to an accelerator tube.

A second equipment used what is now the familiar Cockcroft and Walton voltage-multiplying rectifier arrangement to provide a voltage of 700kV [4]. With this equipment they accelerated protons which were used for the bombardment of lithium and other elements, thus for the first time producing atomic disintegration with artificially accelerated particles[5]. It should be noted that in this work continuously evacuated equipment was used and both rectifiers and accelerator tube were specially constructed for the work. The vacuum equipment used the then relatively new oil-diffusion pumps and it is a matter of some pride in the organisation with which the

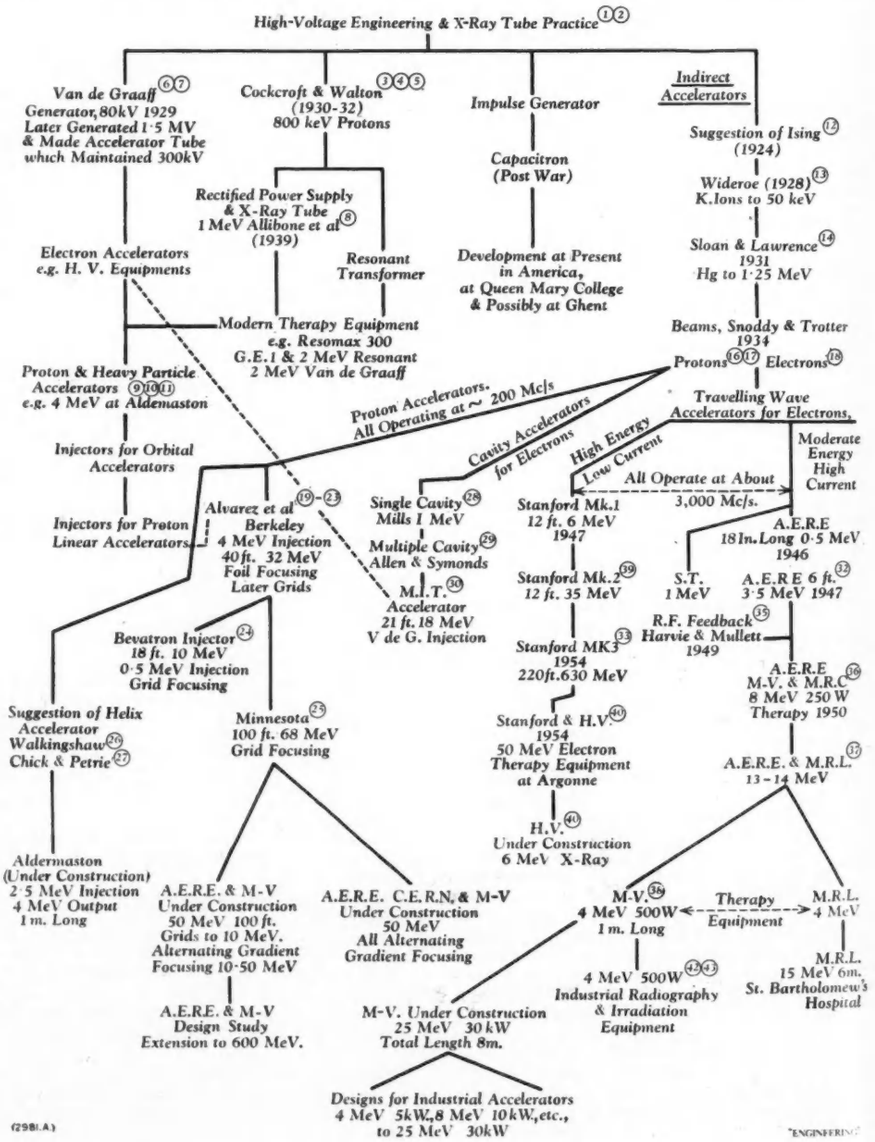

High-Voltage Engineering & X-Ray Tube Practice (1)(2)
Van de Graaff (6)(7) Generator, 80kV 1929 Later Generated 1·5 MV & Made Accelerator Tube which Maintained 300kV
Cockcroft & Walton (3)(4)(5) (1930-32) 800 keV Protons
Impulse Generator
Capacitron (Post War)
Indirect Accelerators
Suggestion of Ising (12) (1924)
Wideroe (1928) (13) K.Ions to 50 keV
Rectified Power Supply & X-Ray Tube 1 MeV Allibone et al (8) (1939)
Electron Accelerators e.g. H. V. Equipments
Resonant Transformer
Development at Present in America, at Queen Mary College & Possibly at Ghent
Sloan & Lawrence (14) 1931 Hg to 1·25 MeV
Modern Therapy Equipment e.g. Resomax 300 G.E.1 & 2 MeV Resonant 2 MeV Van de Graaff
Beams, Snoddy & Trotter 1934
Protons (16)(17) Electrons (18)
Proton & Heavy Particle Accelerators (9)(10)(11) e.g. 4 MeV at Aldermaston
Proton Accelerators. All Operating at ~ 200 Mc/s
Travelling Wave Accelerators for Electrons,
Cavity Accelerators for Electrons
High Energy Low Current
Moderate Energy High Current
All Operate at About 3,000 Mc/s.
Injectors for Orbital Accelerators
Injectors for Proton Linear Accelerators
Alvarez et al Berkeley (19)-(23) 4 MeV Injection 40ft. 32 MeV Foil Focusing Later Grids
Single Cavity Mills 1 MeV
Multiple Cavity Allen & Symonds (29)
M.I.T. (30) Accelerator 21 ft. 18 MeV V de G. Injection
Stanford Mk.1 12 ft. 6 MeV 1947
A.E.R.E 18 In. Long 0·5 MeV 1946
Stanford Mk.2 (39) 12 ft. 35 MeV
S.T. 1 MeV
A.E.R.E 6 ft. (32) 3·5 MeV 1947
R.F. Feedback (35) Harvie & Mullett 1949
Bevatron Injector (24) 18 ft. 10 MeV 0·5 MeV Injection Grid Focusing
Stanford MK3 (33) 1954 220ft. 630 MeV
A.E.R.E M.V. & M.R.C (36) 8 MeV 250 W Therapy 1950
Suggestion of Helix Accelerator Walkingshaw (26) Chick & Petrie (27)
Minnesota (25) 100 ft. 68 MeV Grid Focusing
Stanford & H.V (40) 1954 50 MeV Electron Therapy Equipment at Argonne
A.E.R.E. & M.R.L. (37) 13-14 MeV
H.V. (41) Under Construction 6 MeV X-Ray
Aldermaston (Under Construction) 2·5 MeV Injection 4 MeV Output 1 m. Long
A.E.R.E. & M-V Under Construction 50 MeV 100 ft. Grids to 10 MeV. Alternating Gradient Focusing 10-50 MeV
A.E.R.E. C.E.R.N. & M-V Under Construction 50 MeV All Alternating Gradient Focusing
M-V (38) 4 MeV 500W 1 m. Long
Therapy Equipment
M.R.L. 4 MeV
A.E.R.E. & M-V Design Study Extension to 600 MeV.
M-V. Under Construction 25 MeV 30 kW Total Length 8m.
4 MeV 500W (42)(43) Industrial Radiography & Irradiation Equipment
M.R.L. 15 MeV 6m. St. Bartholomew's Hospital
Designs for Industrial Accelerators 4 MeV 5kW, 8 MeV 10kW, etc., to 25 MeV 30kW
(298L.A)
"ENGINEERING"

Fig. 1 Table showing sequence of development of linear acceleration.

Abbreviations.

H.V. High Voltage Engineering Corporation, America.
G.E. General Electric Company, America.
A.E.R.E. Atomic Energy Research Establishment, Great Britain.
M.I.T. Massachusetts Institute of Technology, America.
M-V Metropolitan-Vickers Electrical Co., Ltd., Manchester.
M.R.C. Medical Research Council, Great Britain.
M.R.L. Mullard Research Laboratories, Salfords, Surrey.
S.T. Standard Telephones and Cables, Ltd., London.
C.E.R.N. Conseil Européen pour la Recherche nucléaire, Geneva.

Numbers in circles refer to references at end of paper.

* Paper read before Section G of the British Association at Bristol on Monday, September 5, 1955.

† Research Department, Metropolitan-Vickers Electrical Co., Ltd.

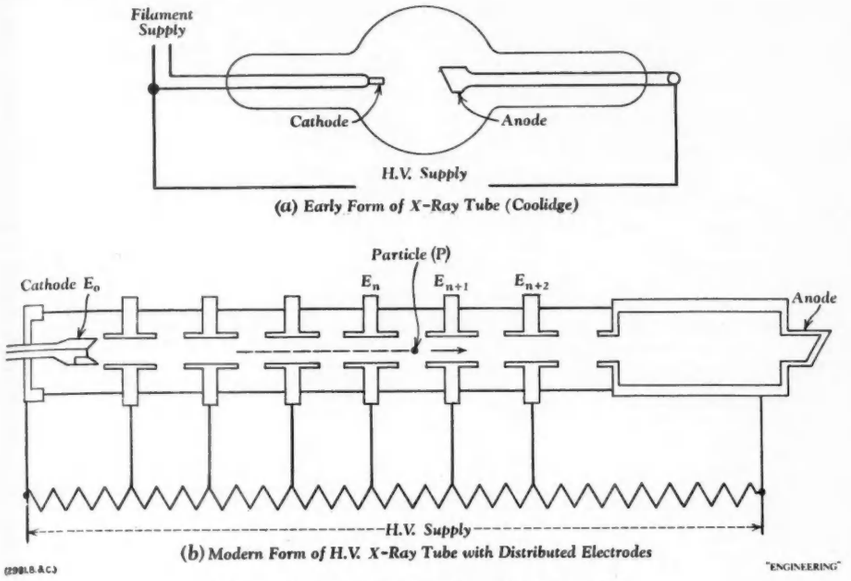


Fig. 2 Early and modern forms of X-ray tubes.

author is associated that it was of assistance in these important experiments, not only in the development of vacuum equipment but also in provision of some of the high-voltage apparatus.

About the same time Van de Graaff, working at Princeton, was tackling the problem in a rather different manner. He was investigating the production of high voltages by electrostatic methods. Various electrostatic generators were already known, including the Wimshurst machine, and several methods of using the principle had been investigated. Van de Graaff's machine, however, employed an endless belt on to which charge could be sprayed and which then transferred this charge to an insulated electrode by means of mechanical motion. In 1929 a model generator was operated at 80 kV, and this was followed by an equipment which could deliver a current of 25 μA at a voltage of 1·5 MV [6]. For use with this generator an accelerator tube was constructed and a potential of 300 kV could be maintained across it[7].

Later, other workers in the field were able to extend the voltage attainable by methods similar to those of both Cockcroft and Walton and of Van de Graaff, and some applications outside the laboratory were soon found. As an early example of such use of the rectifier power supply and a direct accelerator may be quoted the one million volt X-ray equipment by Allibone *et al.*[8] installed at St. Bartholomew's Hospital and still in service at the present time for radiotherapy.

An alternative method of generating high voltage uses the resonant transformer. When operated at fairly high frequency such an arrangement is similar to the Tesla coil; more often, however, the transformers are made resonant at lower frequencies by the addition of shunt capacity and indeed it is common to resonate at the third harmonic of the A.C. power-supply frequency. This, of course, provides an alternating high voltage and use is made of the self-rectifying action of the accelerator tube, e.g., when electrons are provided by a thermionic emitter.

The various forms of direct equipment are found to-day in several standard arrangements. In America the resonant-transformer X-ray equipment has been pressed to as high as two million volts, and experimentally in this country to as high as one million volts. In both countries lower-voltage equipment is standard for either radiotherapy or industrial radiography.

The development of Van de Graaff equipment has perhaps received most attention in America where the work of the High Voltage Engineering Corporation has been particularly noteworthy in developing fully engineered equipment capable of producing not only relatively high voltages but also considerable power. Equipments are now available with ratings of 1 MeV, 250 watts, 2 MeV, 500 watts and 3 MeV, 12 kW. As regards the highest possible voltages a 10 MeV equipment is being constructed at Columbia University[9] and several accelerators are in operation for energies between 6 and 8·5 MeV.[9] Not all the effort on this subject has been on the other side of the Atlantic, however, and some interesting machines have been built in this country. Examples are the equipment for 3 MeV at Harwell[10] and that for 4 MeV at the Associated Electrical Industries Research Laboratory, Aldermaston,[11] illustrated in Fig. 3. Present day high-voltage Van de Graaff generators show some change from the early models and in addition to matters of detail they use improved methods of insulation by employing pressurised gas. At lower voltages considerable attention has been paid to producing compact designs.

As regards accelerating tubes it has become standard practice in direct equipments to use a number of field-equalising electrodes distributed along the length of the tube and these may be maintained at intermediate potentials thus preventing locally high gradients which would lead to breakdown. Thus a modern tube is as shown diagrammatically in Fig. 2(*b*) rather than as in Fig. 2(*a*) which demonstrates the construction of an early form of X-ray tube.

An advantage of direct types of accelerator is their flexibility in being able to deal with various types of particle. For instance the same Van de Graaff generator can be used to accelerate electrons, protons or heavy ions at will. Such equipments inherently provide variability of energy and the Van de Graaff in particular can provide mono-energetic particles with extreme stability.

IMPULSE GENERATORS

Another form of direct accelerator makes use of an impulse generator as the source of high voltage. Such an arrangement was considered by Cockcroft and Walton[4] but dismissed by them at the time as not providing a high mean current. Nevertheless it was the consideration of the impulse generator which led to their voltage-multiplying circuit, this latter really being a modification of an impulse generator in which spark gaps are replaced by rectifier valves thus providing a continuous output instead of a single pulse. The impulse generator is in fact an arrangement in which condensers are charged in parallel from a relatively low-voltage source; they are then connected in series by means of spark gaps acting as switches to provide a high-voltage pulse.

Such equipments have the inherent possibility of providing very high peak powers during the pulse but in their simple forms at any rate provide only low mean power output.

An arrangement using this principle was constructed by the Electronized Chemical Corporation in America shortly after the war and was given the name of Capacitron; it is understood that they are now actively developing a 2-MeV equipment. Work on similar devices is understood to be going on at Queen Mary College, London, and possibly also at Ghent.

For direct types of accelerator a practical upper limit of energy is enforced by insulation difficulties, both in the generator and the accelerator tube. Such a limit may possibly be set in the laboratory at about 5 to 10 MeV but in industrial or hospital use is more likely to be of the order of 2 MeV. It is clear, therefore, that if greater energies are to be reached some method must be devised whereby high energy can be imparted to the particle although voltages between the various parts of the apparatus and between any part and earth remain relatively small. So far as is known the first suggestion of how this problem could be solved was made by Ising[12] in 1924, and such acceleration of particles was first accomplished by Wideroe[13] (1928). In both cases the motion of the particle was linear but it is interesting to note that in the paper in which Wideroe reported his success he also discussed an entirely different method of acceleration in which the particle moved in circular orbits, the now well-known Betatron. Our attention is here confined to the linear machine and before progressing to the different types we shall consider the basic idea of indirect acceleration in an elementary fashion by considering such an equipment as a development from the direct type of accelerator tube.

ELEMENTARY EXPLANATION OF INDIRECT ACCELERATION

We have earlier explained how in a modern direct type of accelerator tube many electrodes are used so that the potential gradient may be maintained constant along the length of the tube. We now consider the motion of a single particle along such a tube. When the particle under consideration, P in Fig. 2(*b*), is between the two electrodes E_n and E_{n+1} it is clear that it is only affected by the potential gradient between these electrodes, that is, by the potential difference maintained between them. Other electrodes are at this moment playing no part in the accelerating process and they could quite well be disconnected. When the particle passes beyond E_{n+1} into the space between it and electrode E_{n+2} it then becomes affected by the potential difference between these two electrodes and the potential gradient between E_n and E_{n+1} ceases to have any effect. It can thus be seen that if a potential difference $\frac{V}{n}$ could be applied successively between the appropriate electrode gaps it would be possible in a tube with n such gaps to attain the same energy of particle as would be obtained if a potential difference V were maintained across the whole accelerator tube for the whole of the acceleration period. In principle such an arrangement could be made if a source of voltage were switched from one pair of electrodes to the next as

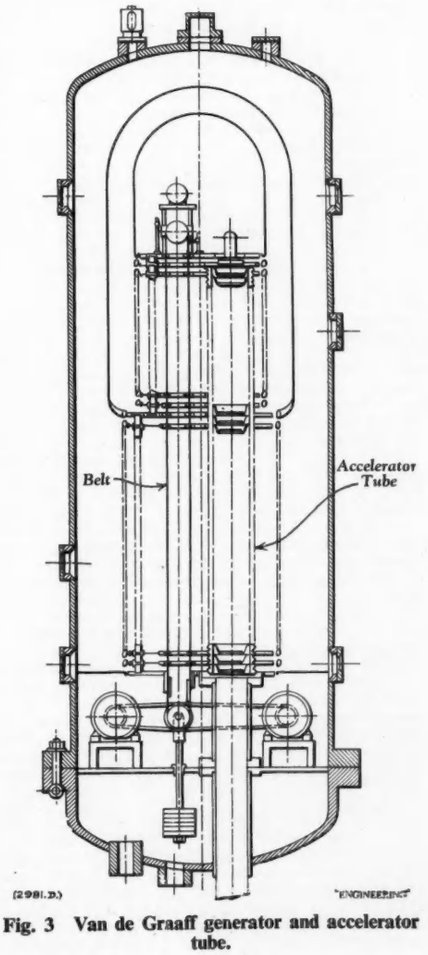


Fig. 3 Van de Graaff generator and accelerator tube.

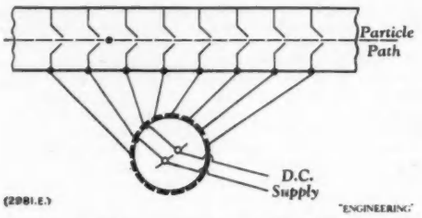


Fig. 4 Indirect acceleration by switching voltage applied to a multi-electrode tube.

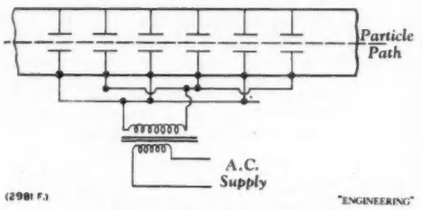


Fig. 5 Indirect acceleration using alternating-current voltage.

the particle progressed along the tube and this is illustrated in the diagram Fig. 4, where the switching is done by means of a commutator arrangement. It is obvious that not all particles injected into such an accelerator would be accelerated; in fact only those injected at the time when the voltage was being applied between electrodes E_0 and E_1 would be accelerated. In practice it is, of course, not possible to operate a mechanical commutator at a speed even approaching that required to follow a particle through an accelerator tube; nevertheless the scheme illustrates the principle of indirect acceleration and has reasonably close resemblance to some of the schemes used in practice.

If instead of using switched direct-current voltages between electrodes as outlined above, alternating-current voltages were used and if electrodes were spaced correctly by some arrangement which screened the particle from any reversal of field it should also be possible to obtain indirect acceleration. In such a case the frequency of the alternating current must be matched to the velocity of the particle and the electrode spacing so as always to provide fields in the right direction, but since the alternating-current frequency can be raised to very high values, i.e., radio frequency, it becomes possible to attain the "commutation speed" required. Such an arrangement is shown in Fig. 5 using the conventional symbols of low-frequency circuits to illustrate the method of connection. It will be noted that now the particle passes through "drift tubes" providing a field-free space between each of the electrode spaces. In these tubes the particle is not accelerated but, as it were, coasts for a length of time sufficient for the field in the next gap to reach the correct polarity for acceleration. In the arrangement shown, this time will need to be one half-cycle of the alternating current and since the velocity of the particle will increase as it acquires energy the lengths of the drift tubes will need to be progressively increased along the length of the accelerator.

At this stage it is profitable to consider the velocities the particles might be expected to attain and as a consequence the alternating-current frequencies we should expect to use. We shall immediately note a significant difference between the treatment required for electrons and that for heavier particles. Using the expressions given at the beginning of the paper we see that all particles approach the velocity of light c as their energy approaches infinity. Using appropriate values for e and m_0 however, we can show that an electron at the modest energy of 50 keV has a velocity $0{\cdot}41\ c$ while at 1 MeV velocity it is $0{\cdot}94\ c$. Thus electrons with energies over one MeV can be considered to have constant velocity very nearly equal to that of light, any increase of energy being shown as an increase in mass. In the case of the proton, however, the increased rest mass causes considerably reduced velocity for a given energy and to be able to consider velocity constant approaching c the particle energy has to be extremely high. Typical values for the proton are 1 MeV, $0{\cdot}046\ c$; 5 MeV, $0{\cdot}1\ c$; 50 MeV, $0{\cdot}32\ c$; and even at 500 MeV the velocity has only reached $0{\cdot}76\ c$. For heavy ions this effect is even more marked. Considering practical lengths of equipment and knowing that one half-cycle of the A.C. frequency must occur in the time of travel from one electrode gap to the next (at any rate in the arrangement represented in Fig. 5) it can be estimated that frequencies of at least 10^9 cycles per second would be required for electrons, 10^6 cycles per second would be suitable for protons, while rather lower frequencies would be adequate for the acceleration of heavy ions. In order to accelerate to appreciable energies it would be necessary to develop considerable voltage across the electrode gaps and so high power would be required from the high-frequency source. How the principles just oulined have been applied will now be described.

MULTI-ELECTRODE EQUIPMENT

Indirect acceleration of particles was first done by Wideroe[13] in 1928. Using applied voltages of some 25 kV at a frequency of approximately 10^6 cycles per second (i.e., a wavelength of about 300 m), he obtained potassium ions with energy equivalent to the direct use of 50 kV, i.e., energies of 50 keV. Wideroe's apparatus is illustrated in Fig. 6 which has been reproduced from the original paper[13]. This shows the accelerator device itself and also the method of energising and the built-in spectrometer for the determination of energy. This equipment used only two accelerating gaps but it illustrated a principle and in his paper Wideroe considers the possibility of using five accelerator tubes, i.e., ten gaps, to accelerate cæsium ions to an energy of 1 MeV. Such an equipment would operate at a wavelength of 175 m ($1{\cdot}71 \times 10^6$ cycles per second), have a voltage of 170 kV across gaps and be of only 1·2 m total length.

The further development of the principle using many more electrodes was carried out by other workers. Sloan, working with Lawrence[14] (1931) and with Coates[15] (1934) accelerated mercury ions to 1·26 and 2·85 MeV. These two equipments used 30 and 36 electrodes and had applied potentials of 42 and 79 kV respectively. The frequency of the alternating current source was approximately 10^7 cycles per second, i.e., considerably higher than that used by Wideroe, and electrodes were connected alternately to opposite ends of the oscillatory circuit.

In the work so far described the apparatus has been of the type illustrated in our elementary consideration using alternating-current feeding of the accelerator and because of limitations on the alternating-current frequency it was limited to heavy ions. An alternative method of energising, more nearly that of the switched direct current description, was investigated by Beams and Snoddy[16, 17] (1933, 1934). They utilised an impulse travelling along a loaded transmission line and connected their electrodes to appropriate points on the line. It was arranged that the velocity of propagation of the pulse along the line matched the velocity of the particle along the accelerator tube. This method permitted higher velocities to be produced and hence lighter particles could be accelerated and indeed protons were eventually accelerated by this method to energies of several MeV, the first success with protons being an energy of 90 keV in a nine-electrode tube with applied voltages of 15 kV.[17]

It is a fundamental property of a loaded transmission line that its velocity of propagation is always less than that of light and since we have seen that electrons travel at almost light velocity if their energy is appreciable it was clear that some modification of the arrangement of Beams and Snoddy was required if electrons were to be accelerated. Such a modified scheme was used by Beams and Trotter[18] (1934) who, by applying their voltage to the electrodes through a number of transmission lines of different lengths could produce the effect of any desired propagation velocity. They achieved acceleration of electrons to 1·3 MeV.

Thus we see that in the pre-war years indirect linear acceleration of various particles ranging from heavy mercury ions through protons down to electrons had been achieved and energies of some MeV attained. It must be remembered that the early workers were faced with considerable difficulty in that they had to work at the limit of existing radio-frequency techniques, both as regards frequency and power. It was not surprising, therefore, that when various orbital methods of acceleration were suggested and experimentally realised, interest in linear accelerators almost disappeared. During the war years, however, radio techniques made enormous progress. In 1939, a frequency of 10^8 cycles per second ($\lambda = 3$ m) was regarded as extremely high and at this frequency powers of only a few hundred watts could be obtained. By 1945, frequencies of 10^9 to 10^{10} cycles per second were commonplace and under the pulse conditions employed in radar, power levels of megawatts were in use. In addition, new techniques of propagation inside hollow conductors (waveguides) had been developed and the properties of resonant cavities had been studied. It was thus clear that the time was appropriate for a renewal of interest in the linear accelerator and as we shall see, the new techniques have been applied to realise large and powerful equipments.

PROTON ACCELERATORS: USE OF WAVEGUIDES

One of the most important properties of propagation inside a hollow conductor or waveguide is that the phase velocity (i.e., the velocity with which we are concerned in matching the wave propagation to the velocity of the particle) is not limited to light velocity as in a transmission line.* Indeed, in the normal smooth-walled waveguide it is always greater than c and, depending on the relationship between the dimensions of the waveguide and the frequency, may take any value between c and infinity. By suitably loading the waveguide (as also applies to a transmission line) the velocity may be reduced and the designer has at his command velocities down to zero. Advantage is taken of this ability in rather different ways depending on the particle to be accelerated, and since interest has been centred on protons and electrons we shall deal with these separately.

Almost all indirect accelerators of protons built so far are based on the use of a resonant cavity form of waveguide in which the phase velocity is made infinite. For convenience such cavities are of circular or near circular cross-section. In the case of the smooth-walled cylindrical guide it is found that phase velocity becomes infinite if the wavelength of the exciting power is 2·61 times the radius of the cylinder, and thus the resonance of such a cavity is independent of its length. Under these conditions electric fields are set up which are parallel to the axis of the cylinder and are in phase at all points along the length of the cavity. Such an arrangement is shown in Fig. 7(*a*). It is found possible to include in such a cavity electrodes or drift tubes which, although distorting the fields and enabling the particles to be shielded from reversals, yet do not prevent the attainment of infinite phase velocity. Dimensions can then be chosen such that the spacing of the electrodes is made to match the particle velocity, i.e., the distance between centres of drift tubes is arranged to be equal to that travelled by the particle in one period of the radio-frequency power and the system can be made resonant by variation of dimensions of individual drift tubes and by choice of the outer diameter of the cavity. The centre-to-centre spacing of electrodes will, of course,

* Dr. H. G. Booker has given an analogy to phase and group velocity which may be found helpful in showing the two velocities associated with a wave. See page 194, *Jl. Inst. Elec. Engrs.*, vol. 94, part III, (1947).

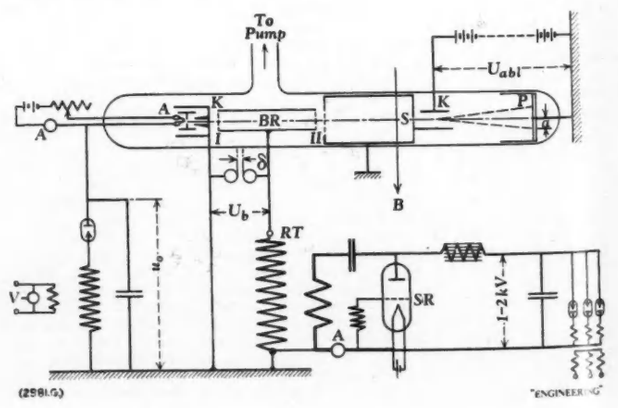
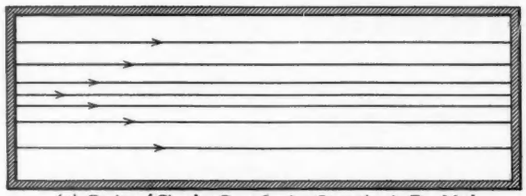
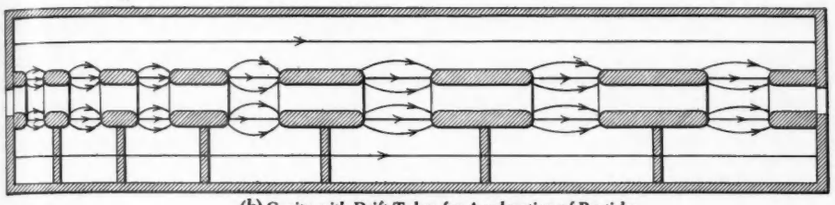


Fig. 6 Equipment used by Wideroe for first demonstration of indirect acceleration.



(*a*) *Cavity of Circular Cross Section Operating in E_{010} Mode Resonant Frequency Dependent on Diameter Only*



(*b*) *Cavity with Drift Tubes for Acceleration of Particles*

(298I.H.&T.) "ENGINEERING"

Fig. 7 Field configuration in resonant cavities.

become progressively larger along the length of the accelerator since the proton will gain in energy and increase in velocity. The arrangement of such a loaded cavity is illustrated in Fig. 7(*b*). For protons of energy of some few MeV, velocity is of the order of 0·1 *c* and electrode spacings become convenient, say the order of 15 cm. when the wavelength of the radio-frequency power is about 1·5 m (200 Mc/s). For this reason, and also because pulse power of high value has become available as a result of radar demand at such wavelengths, most equipments have operated at or near to 200 Mc/s. It can be seen that without electrodes resonance would demand that the cavity should have a diameter of $\frac{3}{2 \cdot 61}$ m and although the effect of the electrodes is to reduce this somewhat the diameter is still of the order of one metre. Since to acquire high energy a large number of electrodes must be used the overall length will be many times the 15 cm. mentioned above and lengths of tens of metres are to be expected. Not all the protons injected into such an accelerator will be accepted or accelerated; indeed, some which are injected at incorrect phasing with respect to the radio-frequency power will be immediately decelerated. Equipments are designed so that protons injected at a particular phase and known as "phase-stable" particles will travel along the accelerator receiving the correct increment of energy at each electrode gap. In general, it is arranged that such particles cross an electrode gap during the time during which the accelerating field is rising but before it has reached its maximum value. It then follows that if, for any reason, a proton should lag behind the phase-stable proton it will acquire an increased increment of energy. Similarly, a proton in advance of phase stability will undergo less acceleration and there is thus a tendency to "bunch" the protons about the phase-stable particle; also the accelerator is able to accept protons injected over a range of phase of the radio-frequency power. There are, of course, many matters of great complexity associated with appropriate dimensional design so that the accelerating fields shall match the required particle dynamics and there is also the matter of the power considerations to produce such fields. These problems are beyond the scope of this paper. We shall now consider the practical realisation of such accelerators.

PROTON INJECTORS FOR SYNCHROTRONS

The first of the modern proton linear accelerators was that built at the University of California, Berkeley, by Alvarez *et al.*[19, 20, 21] between 1946 and 1948. The total length of the resonator is 40 ft. and its diameter is 39 in. It was originally powered from 23 triode oscillators operating so as to produce a pulse of 1·5 MW power, 300 μs long repeated 15 times per second. The output energy is 32 MeV and a pulse current of 6×10^{-8} A was reported in 1948[22]. Considerable improvements have since been made in this machine and in particular the radio-frequency power arrangements have been modified so that 2·1 MW of pulse power is now supplied from a combination of nine single-tube power oscillators and it has three pre-exciter oscillators. Maximum pulse length is 600 μs and a duty cycle of 0·9 per cent. can be used. Performance has recently been reported[23] as being 31·7 MeV and a maximum mean current of 0·37 μA has been attained, this corresponding to a pulse current of about 60 μA. Injection into this machine is from a Van de Graaff generator at 4 MeV. To prevent radial dispersion of the beam Alvarez first used foils on the input ends of each drift tube, the output ends being left plain. This caused a convergence of the electric field and a tendency to focusing. These foils were later replaced by elementary grids which while being more robust than the foils produced the same focusing effect.

Following this first equipment two other accelerators have been built in America. The first of these, also at the University of California, is the injector for the large proton Synchrotron known as the Bevatron. For injection an intense source of protons at an energy of 10 MeV was required and the experience gained with the 32-MeV machine just described was utilised to design a linear accelerator to meet this requirement. Many of the design parameters were a simple extrapolation of those of the 32-MeV machine but there are important differences and, in particular, the linear accelerator accepts protons at the comparatively low energy of 0·5 MeV. The accelerator is approximately 18 ft. long and has 42 drift tubes. It is energised at a peak level of 500 kW by means of three triode oscillators which are tightly coupled to the cavity, and pre-excitation using a tetrode oscillator is employed. The accelerator is energised for pulses of 500 μs duration twice every second but only one pulse in 6 seconds is utilised by the Bevatron. The equipment has been in operation since May, 1953. Energy is quoted[24] as 9·9 MeV and peak pulse current as 75 μA, although this may be increased to 225 μA if the protons are bunched by means of an excited cavity and drift space before injection into the accelerator.

A more ambitious programme is in operation at the University of Minnesota where a 68-MeV equipment has been constructed[25]. This consists of three cavities used in tandem. In the first of these, which is 19 ft. long and very similar to the Bevatron injector, an energy of 10 MeV is reached. In the second stage, which is comparable with the Berkeley 32-MeV set, an energy of 39 MeV is gained. The third stage is similar to the second and in it protons acquire the final energy of 68 MeV. Both the second and third stages are about 40 ft. long and diameter throughout the machine is about 32 in. The operation of three cavities in correct radio-frequency phase relationship involves difficult radio-engineering techniques which are beyond our present scope; several schemes have, however, been considered at Minnesota and a successful solution is dependent upon the type of radio-frequency valve used. It is of interest here to note that the power required for the three cavities are 0·5, 2·5 and 3·5 MW respectively. No proton linear accelerator has yet been built in Britain but one is at present being constructed. It has been designed by the Atomic Energy Research Establishment (A.E.R.E.) and Metropolitan-Vickers in collaboration, and the latter are responsible for manufacture of the equipment which will be installed at Harwell. It will consist of three cavities of 20, 40 and 40 ft. length and in this will resemble the Minnesota equipment. Profiting by knowledge of the previous work, however, many improvements in detailed design and engineering have been incorporated, and in addition there are certain basic differences. The method of providing power will be somewhat different and triode amplifiers driven at a controlled frequency will be used rather than oscillators and special valves have been developed by A.E.R.E. for this purpose. Also, though the usual grid focusing will be employed in the first cavity the remainder of the machine will use magnetic alternating-gradient focusing and it is thus expected that a higher current beam will be extracted. This method of focusing consists of including inside each drift tube a quadripolar lens which is focusing in one plane and defocusing in a plane at right angles. Such lenses are arranged alternately so that in a plane they give alternately focusing and defocusing action this producing a net focusing overall, in the manner now employed in large Synchrotrons. The same principle using electrostatic lenses has been tried on the Berkeley 32-MeV machine and though its usefulness has been demonstrated, it could not be incorporated because of the high voltages required.

The Harwell equipment will produce protons at an energy of 50 MeV. Radio-frequency power is to be supplied in pulses of 400 μs duration at a maximum recurrence rate of 50 per second, and since, of the 5 mA peak current injected at 0·5 MeV, 0·5 mA should be trapped in phase and accelerated in the machine, high output current is expected.

Also being constructed by Metropolitan-Vickers is an almost identical accelerator for the European Council for Nuclear Research, Geneva. This will operate at a much lower duty cycle since it is to be used as an injector for the new proton Synchrotron to be built in Geneva but high pulse currents are still required and indeed, in an effort to obtain maximum performance in this respect, magnetic focusing is being considered as an alternative to grid focusing in the first cavity.

PROTON ACCELERATOR WITH CONDUCTOR IN HELIX

Before leaving proton accelerators some little consideration must be given to an alternative form of accelerator. In those so far described, the velocity of propagation of the radio wave is made infinite and particles are shielded from reversals of field by the drift tubes. It is possible, however, to arrange that the velocity of the wave matches the velocity of the particle and then, provided fields can be arranged to be axial, a particle may travel continuously in an accelerating field. This is a technique used in electron accelerators, as we shall see later, but a rather different form of apparatus is required for protons. If a helix of conductor is excited at radio frequency a wave can be considered to run along the conductor at or about the velocity of light. Its velocity of propagation along the axis of the helix is, however, much less, being reduced approximately in the ratio of the pitch to the circumference of the helix. By suitable arrangement of pitch therefore the velocity of the wave in an axial direction can be made to match the particle velocity. Further, a study of the fields produced shows an axial component suitable for the acceleration of particles injected along the axis. The scheme was first suggested by Walkinshaw[26] and such an arrangement is being constructed at the A.E.I. Research Laboratory, Aldermaston, while work is understood to be in progress on a similar equipment in Belgium. The A.E.I. accelerator will use a helix one metre long and two cm. in diameter of 16-s.w.g. copper wire. Pulse power will be 500 kW at a frequency of 300 Mc/s in pulses of 6 μs duration. Injection will be at 2·5 MeV from a Van de Graaff accelerator and output energy is expected to be about 4 MeV. Focusing is not being considered in the first experiments but later some form of alternating gradient scheme may be added; alternatively the space-charge scheme of focusing suggested by Chick and Petrie[27] may be tried. In this a beam of electrons is injected along the axis in a direction of travel opposite to that of the protons and the concentration of negative charge on the axis provides an attractive force for the protons. It would appear that for acceleration to modest energies where mono-energetic protons of reasonably high energy are already available, the helix, particularly in view of its small size, offers considerable attraction.

The second part of this paper will be in a subsequent issue, which will also contain a list of references.

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Our attention has been drawn to the fact that a possible misunderstanding might arise from our reference to an improved chain-grate contained in our article describing the work now in progress at the British Coal Utilisation Research Association, published on page 770 of our issue of June 17. It should be made clear that a full assessment of the results cannot be given until the grate has been tested under a wide range of conditions. Such tests are, in fact, proceeding at the moment.

MOTOR VEHICLES AND THEIR DESIGN*

A GLANCE AT THE PAST WITH AN EYE TO THE FUTURE

By J. N. McHattie, A.M.I.MECH.E., M.S.A.E.†

The title of this paper covers such a wide field that I can do no more than skim lightly over the surface, giving, perhaps, some idea of the general pattern of the industry. There is one solid fact which is at once the culmination of more than half a century's development and the springboard for future planning, and that is that the motor industry of Great Britain last year produced, for the first time, over a million cars, trucks and buses. As one of the leading exporting industries, and therefore one of the largest dollar earners, the motor industry has every intention of keeping up this rate of progress for as long as possible. Sceptics will immediately say "where are they all going to?" This, however, is not a question which it is within the charter of this paper to explore. It is introduced to lead up to the point that the motor-vehicle designer to-day must think in terms of production by tens or hundreds of thousands annually. This has a profound influence on design.

Quantity production demands broad thinking, and it is no longer possible for one man to cover every aspect of design, let alone production. This applies to cars and light commercial vehicles and, to a lesser extent, to medium-weight commercial vehicles. Heavy trucks and public-service vehicles, being produced in much smaller quantities, present quite different problems.

QUANTITY PRODUCTION

The first step in quantity production is to ensure a steady flow of raw materials, semi-finished parts and finished components to the machine shops and assembly lines. Few people outside the motor industry realise the extent to which manufacturers of the end product—the vehicle—are dependent on specialist processors of raw material, and manufacturers of finished components. Of the six major car-manufacturing companies only one operates a blast furnace, three have foundries, two have press-shops and one or two have drop-forging plant. Only one of these factories has foundry, drop-forging plant and press-shop, but since these facilities were planned the output has so far outgrown their capacity that the factory is dependent on outside supplies for a large proportion of its requirements. The chart in Fig. 1 gives some idea of the complexity of the supply problem, particularly as the flow of material into the assembly plant is in such a wide variety of forms. Moreover, the flow of some materials is so great that it is not economically possible to operate on more than two or three days' stocks.

It follows that the size and complexity of the organisation needed to regulate supplies increase in proportion to the planned output. Taking the industry as a whole, an annual output of 1,000,000 cars demands 5,000,000 wheels and tyres, 8,000,000 brake shoes, about 5,000,000 sparking plugs, 10,000,000 electric bulbs, nearly a square mile of glass, and hundreds of millions of nuts and bolts. These figures take no account of the many items, such as tyres and sparking plugs, which are expendable and require replacement not only on the year's output but on all the other vehicles of varying ages in use on the road. Neither do they take into account the very much greater quantities of every material which go into the heavy commercial and public-service vehicles. A heavy vehicle designed to carry the maximum legal load may weigh five or six times as much as an average car. All these materials must be timed to arrive at the assembly line at the moment and in the quantity needed. The chart in Fig. 2 shows the "family tree" of a typical large automobile factory. Small wonder, then, that the individual who insists on having something a little different must be prepared not only to pay for it, but to wait for it, too.

Machine shops form the backbone of every motor-vehicle factory. In some organisations they are physically separated from the assembly plant simply because both units have become too large to be accommodated in one factory. The incorporation of a machine shop in the vehicle manufacturing organisation is necessary for proper quality control. Inspection at every stage of manufacture is essential, and the greater the number of stages of inspection in each process under one control the better. This consideration, however, must be balanced against the desirability of sub-contracting to specialists.

As steel is, by weight, far the greatest material constituent of a motor vehicle, the motor industry is one of the largest customers of the steel industry, and probably takes more different varieties of steel than any other manufacturing industry. There are many processes in the production of the finished article from steel—rolling into billets, re-rolling into smaller billets and bars, forging, finishing of bars for machining, rolling of strip, plate and sheet, and wire drawing, to name but a few—and each process is an industry in itself consisting of a number of specialist concerns. In some cases the entire chain of processes is controlled by one group, which has the advantage that the progress of each type of steel is closely regulated to the needs of each department. On the other hand, the smaller independent units, each competing for supplies of material and for orders from manufacturers, retain a flexibility impossible in a large organisation.

AUTOMATION

In an earlier period, when manpower was plentiful, machine tools were an expensive luxury and manual processes, particularly in the movement of material, were economical. With the growing shortage and cost of manpower, ways had to be found to increase the productivity of each man. This has led to the development of—to use an abominable but useful Americanism—"automation." Although the word is of post-war origin, the principle is as old as the industrial revolution, if not older.

Automation—the handling of materials and processes by machine instead of by human labour—has the advantage of eliminating to a large extent the fallibility of human beings, but at the same time it sacrifices their infinite flexibility. It can be, and is, applied with equal success to machine tools and to assembly lines. This success, however, can be maintained only by a very high standard of accuracy at every stage. One of the latest developments, and the one, I believe, which brought about the coining of the word "automation," is the introduction of transfer machines. Until recently the various machining processes, milling, boring, drilling, tapping, and so on, were performed by individual machines of different makes, each probably working at a different level. These machines could be set up to perform a variety of jobs, and were used mostly in conjunction with separate jigs and fixtures. In a transfer machine the various processes are grouped, and the various units of the machine are designed and built to perform one task. The component is fed in at one end in the rough state, and is passed mechanically from one machining unit to the next, emerging finally as a completely machined article. Transfer machinery can be

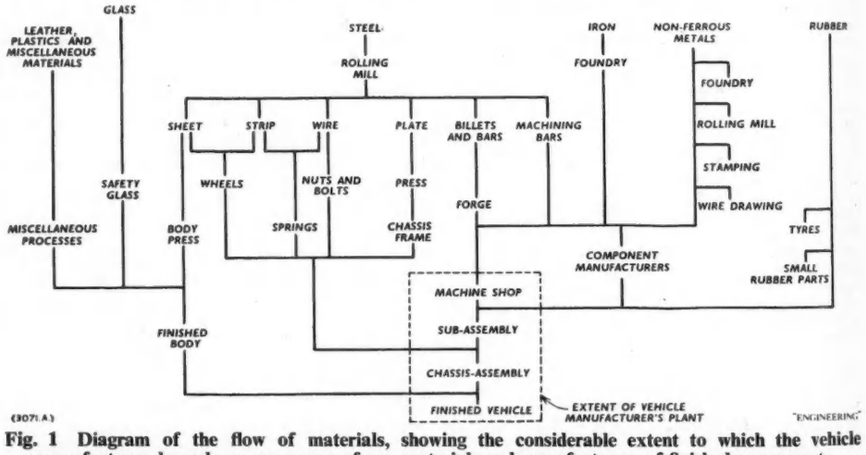

Fig. 1 Diagram of the flow of materials, showing the considerable extent to which the vehicle manufacturer depends on processors of raw materials and manufacturers of finished components.

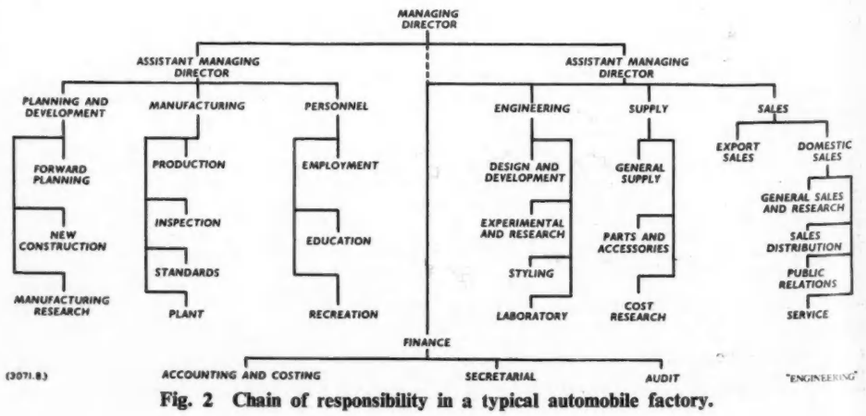

Fig. 2 Chain of responsibility in a typical automobile factory.

* Paper read before Section G of the British Association at Bristol on Monday, September 5.

† Technical officer, Society of Motor Manufacturers and Traders.

used economically only on relatively large components such as cylinder blocks or gearbox casings in which the design is fairly stable. The alteration in the position of one hole as a production modification might necessitate major resetting of a machine.

Material handling is now a flourishing industry in its own right, and only a factory producing large, bulky articles in very small numbers can afford not to be fully " conveyorised " nowadays. The conveyor has been used in various forms for many years, the earliest example of the mechanical conveyor which springs to my mind being those fascinating devices which at one time were extensively used in department stores for the distribution of change from a central cash desk. Another important contribution to the economical handling of material is the stillage, and its conveyance, the fork-lift truck. Automation, however elementary its form, entails relatively high capital outlay, and its use can be justified only if this outlay can be spread thinly over a very large number of products.

Considerations of material availability, economy of manufacture and ease of assembly have a profound influence on design. There is another factor, which, from the buyer's point of view, does not get nearly as much attention from designers as it deserves, and that is serviceability.

DESIGN AND LEADERSHIP

Accessibility is frequently sacrificed at the altar of expediency or, still worse, for the sake of styling. In these days of specialisation, when each unit of a vehicle is designed by a separate team, it is difficult to ensure that each part is studied not only in relation to its own function and those of its immediate neighbours, but also in relation to the design as a whole. This collaboration is essential if the vehicle is going to be as economical to maintain as it is to manufacture, and the cost of maintenance is a direct reflection of the quality of leadership of the design team as a whole. The collaboration of the service department in the design should be taken for granted by every manufacturer from the start.

Design, at least as far as motor vehicles are concerned, might be defined as the art of successful compromise. The first question for the car designer is " what does the public want ? " The answer is, of course, that the largest proportion of potential buyers have not the faintest idea what they do want, but rely on the automobile engineer to provide it. A smaller, but much more vociferous, section knows exactly what it wants. Moreover, each individual wants a different specification, but if a car were made to any of these specifications its cost would be astronomical. The designer of commercial vehicles, and particularly of public-service vehicles, has a much more realistic and long-headed type of customer who not only knows what he wants, but also how much he is prepared to pay for his vehicle and its maintenance.

Car designers must therefore think in larger quantities and take a bigger gamble on the success of their designs. Having formed the basic idea of what he thinks should appeal, the designer must then plot a complicated course through a whole series of Scyllas and Charybdises in the form of quantities, prices, legislation, material availability, production facilities, standardisation, convention, new ideas under development, new ideas which might be developed, demands of the sales and service departments and financial limitations.

There are two distinct approaches to the design of any manufactured article. One is to cater for the connoisseur by using the best possible materials and workmanship, providing the most lavish equipment, and letting the price take care of itself. This market, is of course, strictly limited. The other approach is to set a price target in a highly competitive market, and provide the best possible article within that price. Between these two poles there are various shades of specialised products for a variety of uses. In the motor industry, manufacturers who specialise in anything from municipal refuse lorries to competition or racing cars all have their own assured, if restricted, markets. It is only once in a while that a designer is lucky enough to have the opportunity of starting an entirely new project. Almost all current models have a long history of gradual development. Even if the outward appearance of a new model is completely fresh, strong evidence of a family likeness to its predecessor can usually be found internally. Sometimes the reverse is the case, but the obvious line of development when a falling-off in demand calls for a change of model is to dress up the old working parts with new " sales appeal," and to introduce structural or power-unit changes at leisure.

Legislation is nearly always of a restrictive nature, and is usually brought about by public demand for safety measures. Occasionally measures of relaxation are brought in as a result of pressure by the industry. In later years a better understanding has grown up between industry and Government departments, and each now has a better appreciation of the other's problems. Consultation before the introduction of new measures gives the designer some indication of what may be expected of him, although he is taking a long chance if he goes into production with a design based on proposed legislation.

STEEL v. NEW MATERIALS

Steel always has been, and probably always will be, the basic material for motor vehicles of all kinds, although there have been many attempts in the past to substitute light alloys. It is clearly apparent that in the future plastics will make a strong bid for ascendancy. There are many reasons why alternative materials have not ousted steel, the main one being price. Steel can be worked, machined, welded, painted or plated with a reasonable degree of certainty that results will be consistent. Manufacturing plant and processes can therefore be planned with the knowledge that long production runs can be expected with a minimum of hold-ups. The capital cost may be very high, but it can be spread very thinly over a large output.

Although manufacturing techniques in light alloys have made great strides, the processes as well as the raw materials are still more expensive in this country. In the more specialised field of public-service vehicle body construction, where quantities are small and low weight may pay for high first cost in terms of extra seating and consequent revenue, light alloys have an assured future, and with the development of the technique of extrusion their application has been considerably extended, but for private cars they will probably remain something of a luxury.

To the general public the word " plastics " still seems to hold some promise of magic. They are mysterious concoctions created by chemists from the most unlikely materials, and are capable of production in an unlimited range of shapes, colours and consistencies better and more cheaply than anything hitherto available. There is no doubt that the scope for plastics in motor-vehicle construction is enormous, but it is not unlimited. For small details, finishing, ornamental work and so on, they are extremely useful, but as structural materials for quantity production they are not quite so promising. For bodywork their most suitable application is likely to be the specialist type of " one-off " production where, although raw material costs are high, manufacturing costs are comparatively low and no limitations on shape are imposed by the nature of the material. Although with plastic panels the tooling costs are low, the production cycle is very slow.

STANDARDISATION

Standardisation is a much misunderstood subject. It can be at once the servant and the master of the engineer; a millstone round his neck and an economic blessing. Improperly understood and misused, standardisation can mean stultification. On the other hand, it can lead to the economical production of large quantities of a component or material common to a number of different uses, and is a valuable aid to reducing the amount of capital locked up in stocks for original use and replacement. Broadly speaking, standards can be divided into four main categories. These are: (1) dimensional standards, which aim to reduce costs of production and servicing, and assist interchangeability; (2) quality standards, which aim to set a minimum specification and to influence the development of suitable materials; (3) performance standards, which aim to some extent to anticipate safety legislation in matters such as lighting; and (4) test standards, which aim to unify test procedures and the expression of performance. The adoption of any of these standards is at the choice of the designer. Obviously, as they offer advantages, there are attendant disadvantages which must be weighed against them. The test of a good standard is its flexibility, allowing the advantages so far to outweigh the disadvantages that its adoption is an economic proposition.

There are large numbers of established standards which have been developed by manufacturers and users working in collaboration. These standards are necessarily of very general application, and most industries have developed their own standards for more specialised uses. Farther down the scale some of the larger manufacturing concerns have found it worth-while to create their own domestic standards. The process of standardisation is, however, continuous, and to-day's domestic standard may be to-morrow's national standard.

Comparatively few buyers of cars are particularly interested in the internal workings of their vehicles, provided that the expected performance results from the operation of the appropriate controls. Still fewer are aware of the immense amount of detail work which keeps large staffs of designers and draughtsmen in continuous employment. Design is not a matter of creating a new model and sitting back until it is time to create another. That is the prerogative of the brilliant genius whom most down-to-earth manufacturers are reluctant to employ. Design is, rather, a continuous process conducted by a team, and it is not always expedient to arrange that the efforts of each section of the team shall reach fruition at the same time.

It is a peculiar fact that, however carefully and exhaustively a new product is tested by factory personnel, it rarely gives an indication of all the troubles which will develop as soon as it gets into the hands of the customer. This is largely due to the fact that prototypes cannot be produced by quantity-production methods. It is indeed fortunate that there always seems to be an adequate supply of keen buyers who are willing to risk the inconvenience of teething troubles for the pleasure of owning an entirely new model. All new models have teething troubles. It is not, however, the troubles themselves which affect the subsequent reputation of the vehicle so much as the way they are dealt with. The manufacturer must therefore be prepared to spend money—a large amount if necessary—on decisive modification. Much time, money and goodwill can be wasted on half-measures.

A model which is fundamentally right will run for many years, although its later forms may bear little or no resemblance to the original. Several current examples will readily come to mind of popular cars which have continuously maintained a tradition as well as a model title, although they now have nothing else apparently in common with their forebears. In most cases the basis is a successful engine, which has outlasted successive changes in styling and has been finally replaced by an engine of more advanced design and considerably higher performance.

RESEARCH

Many designs in the past have turned out to be highly successful without their originators being able to say exactly why this should be so. If the reasons for success are unknown it is a matter of pure chance whether or not the incorporation of the same feature in other models will repeat the success. This is where research comes in. The motor industry, in common with most other industries, spends large sums of money and maintains costly establishments for research,

not only to find out what happens, but, equally important, to find out why it happens. The layman must find it difficult to understand why so much time and money are spent in achieving apparently insignificant results. Research on all kinds of technical problems of a general nature is carried on by the Motor Industry Research Association, which also maintains a proving ground for the use of its members. Here individual manufacturers can test their products or prototypes in conditions simulating as nearly as possible those met with in all parts of the world. Road surfaces of all kinds are fairly simple to copy, but it is not so easy to reproduce atmospheric conditions and there is really no satisfactory substitute for testing under local conditions.

This accounts, to a large extent, for the success of American vehicles in world markets, because the home market in the United States, which absorbs about 95 per cent. of the motor industry's output, stretches from the humid heat of the tropics, through desert dust to the sub-zero temperatures of the Arctic regions. All this with a highway system second to none where continuous high speeds are not a luxury but a sheer commercial necessity. In addition to general research and testing, each manufacturer maintains an experimental department varying in size from a small shed at the back to a full-scale research establishment complete with proving ground. In view of this, the layman might be tempted to ask " How is it that small concerns are able to produce highly successful vehicles without the benefit of costly research?" There is no simple answer to this, but broadly speaking the " cut-and-try " methods practised by some of the smaller firms would be a great deal more costly in terms of large-scale production than an expensive research department.

TRENDS AND PHASES

For the purpose of this paper I have adopted the definitions of trend as the general direction of development, and of phase as a significant deviation from the trend. If one is to make an intelligent guess at the future, it is not enough to study the present direction of the trend. One must look back to see where the line of development has come from. The line of development of mechanised road transport, which started just before the beginning of this century, has been broken by two world wars, both of which had a profound influence on the course of design. They could be likened to the injection of a powerful stimulant with a delayed action and unpredictable side-effects. The years before the first World War were the formative years. Engineers were grappling with entirely new problems, without a precedent to guide them. A period of adolescence followed the first war, and many promising but fruitless ideas were tried out. The intense competition brought about by the slump of the early 'thirties tended to stabilise design to a marked degree, so that by the time of the second World War the motor industry was firmly established as one of the major industries. The seller's market which followed enabled the industry to consolidate its position and determine its line of development.

From the very beginning domestic needs have governed all development from the more or less common origin of the horse-drawn vehicle. In Great Britain and on the Continent of Europe the dog-cart was the basis; in America, the buggy. It was natural that in America, faced with the sheer physical necessity of covering long distances, the automobile was regarded from the first as a purely utilitarian form of transport. Long journeys on unmetalled dirt roads, and the availability of ample cheap fuel led designers to concentrate on the necessities, which were plenty of power and a comfortable ride. Political and geographical considerations on the Continent divided the lines of development sharply into luxury transport and the starkest utility. Very bad roads focused attention on suspension, and long stretches of straight road demanded high efficiency and durability with economy.

In the United Kingdom it was a long time before road transport was taken seriously, consequently the car started as a luxury vehicle and worked downwards towards utility. The British buyer has therefore always tended to take for granted what in other countries would be regarded as luxuries, and to reject any vehicle which falls below a certain standard in this respect, however insistent the call for economy. Narrow, winding roads made high speed capabilities unnecessary, but demanded first-class steering and good acceleration. Excellent road surfaces, even on almost uncharted tracks, made springing practically unnecessary, and as journeys were relatively short, the hard springing which went with good steering was tolerated.

It was not until 1945 that world economy compelled certain countries to export a high proportion of their manufactured products in exchange for food. For the first time in its history, the motor industry of Great Britain had to take its exports seriously, and the realisation was a somewhat painful one. Having by dint of much sweat and toil become the leading exporter of motor vehicles, Great Britain must at all costs maintain that position, even if it means the home market having to tolerate some deviations from what it considers a motor vehicle should be. With her background of home market restrictions in size and speed showing little prospect of significant change within the next five or ten years at least, Great Britain faces a harder task than any other exporting country in satisfying world markets. Nevertheless, the handicap is being overcome as experience in catering for world markets is being gained.

Having roughly plotted a few points in the development curve, I now propose to follow the curve in slightly greater detail. Up to about 1905 engineers, having only the horse-drawn vehicle to guide them and finding that petrol-fed horses were so much more compact, yielded to the temptation to hide their horses under the floor or seat. The fact that in this position they were wholly inaccessible did not seem to occur to their designers. The year 1905 ushered in what in veteran motoring circles is known as the Edwardian era. By this time a more or less orthodox pattern had been established. An engine of four or six cylinders in line, mounted just behind the front axle, drove through a clutch, gearbox and propeller shaft to a live rear axle. The driver and passenger sat amidships, and if it was conceded that more passengers should be carried, they were perched precariously over the back axle. This convention persisted until the first World War, during which technical development moved by leaps and bounds. As a result, designers found much more compact horses at their disposal. The awakening of the public to the possibilities of road travel, the price of fuel, and economic conditions generally, led to a demand for a small family car, so the back seat was formally incorporated in the body and, at the same time, the whole seating plan was moved forward.

STYLING

At this stage another trend developed. From the beginning the car owner had been fair game for the accessory merchant, who had it all his own way with the supply of what were now coming to be regarded as necessities—lamps, horns, speedometers, hoods, screens, spare wheels, and so on. The stress of competition following the first World War led manufacturers of the vehicles to supply these items as a matter of course, at the same time offering many of the less necessary gadgets as optional extras. Then came the slump of 1930, and with it developed a struggle for survival so fierce that many worthy designs and sound engineering jobs were sunk without trace. Technical development made considerable strides during this period, but mostly in the direction of cheapening the product. At the same time the insistent demand of the salesmen for features which would make their products easier to sell led to a revolution in styling. In fact, it led to the introduction of styling as we know it. Gradually the accessories which had become standard fittings became merged more and more into the outline of the car.

This was, broadly, the situation when the second World War broke out. At the end of hostilities most manufacturers took up their pre-war designs where they had left them, and endeavoured with these to stem the overwhelming tide of demand. A few others made bold guesses at the shape of things to come and produced entirely new styles. Meanwhile the export markets, which the economic situation compelled us to nurse, were giving an indication of the direction in which public taste was leading.

THREE POST-WAR PHASES

It was at this stage that car manufacturers' planning took definite shape. As all manufacturers faced the same set of circumstances it was natural that their planning fell into a general pattern. It was immediately recognised that the pre-war models would not be accepted for long, particularly in export markets where the more advanced American models had been available. There are limits to the fashions which even the most car-hungry public will tolerate. It was further realised that it would be difficult, if not impossible, to step straight from pre-war styles to those which were taking shape on the drawing-board without some intermediate steps. The advance was therefore planned in three steps. Pre-war models, production of which had been resumed, became known as Phase I models. The interim models in which advances in styling, such as built-in headlamps and larger luggage boots, or advances in technique such as independent front suspension and the steering-column gear control, were introduced became Phase II models. Phase III was the final step in the transition period, in which overall changes in styling and technical improvement were adopted. The pattern of full-width bodywork, one-piece bonnets, inter-axle seating, independent front suspension, overhead-valve engines, steering-column gear changes and hypoid bevel rear axles, which emerged as Phase III, became more or less standardised as the jumping-off point for future development. It is not always fully realised that the time needed for the design, development and tooling of a new model for volume production is not less than two or three years.

Throughout the history of the motor vehicle, engineers have been tempted to stray from the path of normal development to explore some promising by-way. Many of these have ended up as culs-de-sac. Some, after winding inconsequentially hither and thither, have led back to the main road. From time to time these by-ways have run a long way before petering out, and have been well worth exploring for their own sake, even although a notice at the beginning said " No Through Road." Without these explorations the field of human knowledge would be an uncharted waste, traversed by a few obvious but dreary paths. Let us therefore be thankful for those bold spirits who have rated the search for knowledge higher than mere commercial advantage.

In the formative years before the orthodox in design became a well-trodden path, these excursions were an everyday occurrence. The period following the 1914-1918 war produced a sharp division in the approach to motor-vehicle design. On the one hand was the sound engineering and relatively slow development of the designers who had found their feet in the Edwardian era. On the other hand, there was an outbreak of fantastic designs, many of them the brain-children of aircraft engineers, which were doomed to failure from the start. It is with no little regret that one looks back to that period, because it saw the birth of a number of brilliant ideas whose only fault was that they were years ahead of their time. Premature birth has undoubtedly been responsible for the high mortality rate of promising ideas which, given the knowledge, materials and production methods of to-day, might have changed the entire course of technical development.

It is an unfortunate characteristic of many geniuses that their brains work so much faster than their hands that by the time their visions have reached a three-dimensional stage they have

lost interest in them. It is difficult for the painstaking development engineer to keep pace with such genius, and in consequence many promising designs have failed through lack of follow-through development. True genius has been defined as an infinite capacity for taking pains. The few examples of men who have been sufficiently single-minded and tenacious to press their ideas to a logical conclusion are so outstanding as to furnish ample proof of the truth of this definition. For every genius whose name becomes a household word, however, there are hundreds who earn the title by their capacity for taking pains, but who remain behind the scenes and form the backbone of the creative side of the motor industry.

By no means all those who have good ideas have the facilities for developing them, as a study of the files of the Patent Office will show. The engine and transmission have always stimulated inventors, but of the innumerable ideas for improvement of valve gears alone only a very small proportion are even practicable. From the very earliest days, the infinitely-variable gear has been an irresistible attraction, and some designs have even been put into service, but so far nobody has solved the problem of providing stepless changes of ratio without friction, fluid, or electricity, all of which involve intolerable loss of efficiency.

Although as far as cars are concerned design appears to have crystallised into a fairly uniform shape, this is not the case with commercial and public-transport vehicles, in which plenty of evidence can still be found of a fresh and unconventional outlook. The compression-ignition engine, although as old in principle as the spark-ignition engine, has lagged behind in the development of its application to road transport, and still offers exciting prospects of discovery. The current attraction of high thermal efficiency is creating a demand strong enough to stimulate development and to encourage the exploration of uncharted ways, and the re-exploration of ways which, in the light of previous knowledge and facilities, did not seem to lead to a profitable goal.

PROSPECTS

In a review of prospects the first essential is a realistic assessment of the present position, and the governing factor in any form of propulsion is the availability of fuel. At the present moment the Diesel engine is challenging the ascendancy of the petrol engine, but in fact the fortunes of the two rival types are closely bound together.

An aspect which is sometimes overlooked is the natural balance of fuel supplies. It is, perhaps, an over-simplification to say that every barrel of crude oil drawn from the earth yields predetermined proportions of lubricating oil, fuel oils and high-octane petrol, as well as a host of other by-products. If there is an inordinate demand for any one of these products at the expense of the others, the price will be adjusted to restore the natural balance. The world's supply of oil cannot be inexhaustible, but meanwhile there is plenty of it. Nevertheless, world economy cannot afford to countenance the waste of much of what is drawn from the ground.

The internal-combustion piston engine is therefore still a force to be reckoned with, and designers must still pander to its characteristics and its inherent shortcomings. In its most efficient form the internal-combustion engine is an inflexible brute, and will only give of its best at one speed. The larger the engine, therefore, the greater the margin between its comfortable operating speed and its ultimate output, and the longer its life.

In America at the moment a great deal is heard of the " horse-power race." Without inquiring too closely into the methods of measuring the astronomical outputs claimed, one can see that ultimate maximum power is being aimed at regardless of performance at the lower end of the speed range, due to the real need of power for quick overtaking on congested high-speed roads. At the end of the last war 100 brake horse-power was a normal maximum output. By the time output reached 150 brake horse-power, it was clear that the side-valve engine commonly used was nearing the limit of its development. Overhead valves were adopted almost throughout the industry, and the hemispherical combustion chamber, which had been used on high-performance engines in Europe for many years, was " discovered." There was a swing-over to the compact V-8 engine of 200 brake horse-power and upwards. The figure is now passing the 300 mark. I am tempted to suggest that a great deal of trouble would be saved all round by the introduction of a new unit to be known as " a.h.p."—advertised horse-power.

AUTOMATIC TRANSMISSION

The horse-power race would not have been possible without the automatic transmission. This accommodating device looks after the lower speed range so effectively that it covers up the deficiencies brought about by too much attention to the upper end of the power curve. European designers are not so fortunately placed. The size of their engines is strictly limited, and the comparative inefficiency of a hydraulic transmission cannot be tolerated in an engine which spends so much of its time transmitting its power through the lower gears. If flexibility is to be sacrified to high-speed efficiency, greater use must be made of the lower gears.

The proportion of drivers who use their vehicles for transport only, and have no interest in the finer points of driving, is increasing and will continue to increase. They cannot be expected to understand the most efficient use of the gearbox and for them the manual change must, in time, be eliminated. The problem, therefore, is to evolve an automatic torque-converting device which does not absorb too much power in the process of converting. The most efficient practicable torque converter is the straightforward mechanical gearbox. There are numerous ways of turning this into an automatic transmission, but so far they are too costly and complicated to be acceptable. Furthermore, a problem so far unsolved, and for which it is hard to visualise a solution, is that of designing a gearbox which will not only interpret the needs of the engine, but will anticipate them. To be fully effective, the gearbox should be about 100 yards in front of the vehicle. I do not believe that the problem of the automatic transmission is insoluble, but the question is, will it be solved before alternative types of power unit render the automatic transmission unnecessary?

GAS TURBINE AND ATOMIC POWER

The next logical step in power-unit development would seem to be the gas turbine, although this is still many years ahead. With the evolution of atomic power, the scope of which is apparently unlimited, the gas turbine might well have to yield to the steam-driven turbine even before it has developed to the production stage.

The growth of the market for road vehicles is dependent largely on the provision of adequate roads. Hitherto vehicles have been developed to suit the roads in a negative sense. In other words, they have been designed to cope with road conditions worse than those which would now be considered normal. Whether the road programme of this country will ever catch up with traffic requirements appears doubtful. Nevertheless, road engineers throughout the world are now planning, or have already constructed, highways designed for the road traffic of the future. At the moment, vehicle designers are faced with a transition from roads of the past to roads of the future, and they must provide vehicles suitable for both. There is even a tendency, particularly noticeable among heavy-vehicle manufacturers in America, to produce highway vehicles for long, fast hauls, and " off-the-road " vehicles for undeveloped territory.

A faint echo of this trend is discernible in cars. The war-time Jeep set a fashion in off-the-road personal transport which has caught on, particularly among farmers. Meanwhile the normal American car is becoming more of a highway vehicle and less suitable for narrow, winding roads, steep climbs and rough going generally. This is a natural development in a country which has the most advanced road system in the world, and that is why America leads the fashion in highway vehicles. As far as styling for its own sake is concerned, however, America has lately drawn much inspiration from the Continent, and the improvement in line and proportion has been most noticeable.

Styling cannot be truly successful without a functional element. It is true, in fact, of any work of man that it looks best when most nearly suited to the job for which it was designed. The primary function of a passenger vehicle is to enclose a specified number of human beings in a comfortable envelope in which they can be conveyed from place to place with a minimum of inconvenience. As the human form adapts itself very little to changing fashions, it follows that the shape and size of the passengers is the ruling factor in the shaping of a vehicle body. It is therefore impossible, having arrived at a successful and pleasing shape for a large vehicle, to scale it down for a smaller one, and the European car will, for this reason, never be able to emulate the low, sleek lines of its American counterpart until the highways and the standard of living of the world reach the level at present enjoyed in America.

To forecast with any hope of accuracy what the car of the future will look like is impossible, because there are so many factors which it is outside the compass of the human mind to predict. Very early in the history of the motor car it was realised that wind resistance was the enemy of speed. From that time steady progress has been made in reducing the frontal area and smoothing off projections, the aim being the streamline shape or " teardrop " which wind-tunnel tests have proved to offer least resistance to swift passage through the air.

FROM WIND-TRAP TO SUN-TRAP

No advance has been achieved without yielding ground at some stage, and it has been found that the less a car becomes a wind-trap, the more it becomes a sun-trap. The passengers are apt to feel like butterflies in a glass bottle, exposed alike to the rays of the sun and the gaze of the public. Furthermore, the angle of the glass in relation to brightly plated or light coloured instruments and controls gives rise to unpleasant and distracting reflections. The answer to this, supplied with alacrity by accessory merchants, is to cowl everything over—windscreen, instruments, headlamps and even tail lamps. These accessories are rapidly becoming absorbed into transatlantic styling, with the result that cars are now not so much wind-traps as wind-scoops. There is no doubt in my mind that some less obvious solution to the problems of glare, dazzle and reflection will eventually be found, and that styling will revert to a more refined form of streamlining, probably with the extension to functional dimensions of the stabilising fins which are already appearing in rudimentary form. These will be necessary if really high speeds become generally used.

Highway vehicles of the future will be propelled at sustained high speeds along carefully graded and superelevated roads. Gearboxes will be necessary only for starting and for manœuvring off the highway, and two-pedal control will become universal. One can even visualise a time when the steering wheel will become redundant, its function being performed by electronically-operated controls sensitive to " beams " built into the road surface. The driver will have no more to do than the driver of an electric train on a system completely controlled by track-circuiting. The prospect is not so alarming as it might seem to those who enjoy motoring as opposed to pressing buttons and watching signals, as there will always be available a considerable mileage of secondary and third-class roads, even if these have to be carefully " preserved " like ancient monuments, for the edification and enjoyment of those whose tastes linger nostalgically with the past.

AN ELEMENTARY INTRODUCTION TO SOIL MECHANICS*

By P. L. Capper, T.D., M.SC.(ENG.), M.I.STRUCT.E., A.M.I.C.E.†

Although soil has been in use by mankind longer than any other engineering material, it is only in comparatively recent times that scientific study has been systematically applied to it. The term Soil Mechanics only dates from 1936, when the first International Conference on this subject was held at Cambridge, Massachusetts. Soil mechanics has been defined[1] as "the application of the laws of mechanics and hydraulics to the use of soil for engineering purposes." Before discussing the relationship of this new science to the much older science of geology, it is necessary to define what is meant by "soil." Geologists use the term "rock" to include all the materials of which the earth's crust is composed, irrespective of their physical characteristics, and describe as "soil" only the "A, B and C horizons" of weathered deposits. The engineer restricts his definition of rock to natural beds or hard fragments of the original solid igneous, sedimentary and metamorphic rocks. He uses the word "soil" in a more comprehensive sense to include all sediments and deposits of particles formed by the disintegration of rock.

Soil in the engineering sense necessarily forms, in its natural condition, the foundation for all works of construction, except where these can be founded directly upon solid rock. It is also extensively used as a constructional material, for example, in embankments, dams and earth roads. As with other engineering materials the use of soil for these purposes necessitates a knowledge of their physical and mechanical properties. The study of these properties and of their application in engineering work is the main purpose of soil mechanics.

THE SCOPE OF SOIL MECHANICS

In designing any member of an engineering structure four points have to be considered: (i) the loads or external forces applied to the member; (ii) the internal forces and stresses set up in the member; (iii) the deformations produced; and (iv) the way in which failure will take place if the member is overloaded. The same applies to soil; but compared with other materials of construction soil presents greater difficulties on account of its lack of uniformity and its susceptibility to changes in its properties arising from variation in the water content. Soil mechanics comprises three main divisions: (i) the mechanics of soils, that is, the laws of equilibrium, stress distribution and movement of water in soil; (ii) site investigation and the testing of soil for the determination of the relevant properties; (iii) the combination of the findings under the first two headings for civil engineering design and construction.

Looking back on the history of soil mechanics, four phases in its development may be traced. The first phase, which extended to the first quarter of the present century, was one of empirical methods. It is true that Coulomb's law of shearing resistance was known, but it was practically ignored; for retaining walls the classical earth pressure theories of Coulomb and Rankine were used indiscriminately, often under conditions where the basic assumptions of the theories were far from valid.

In the period between the world wars, engineers and physicists began to study soils and their properties on a more systematic basis. Special tribute must be paid to that pioneer of soil mechanics, Dr. Karl Terzaghi, whose work, both theoretical and practical, has done so much to establish the new science and to stimulate interest in it in all parts of the world. At that time, which may be regarded as the second phase, special attention was paid to the classification of soils, so that the identification of a particular type of soil would indicate its characteristic properties. The study of soil mechanics has shown that something more is required. The third phase, therefore, was to develop tests for the direct determination, from laboratory tests on undisturbed samples, of fundamental properties such as shear strength, compressibility and permeability.

The difficulty of obtaining samples which are really undisturbed, and discrepancies between the properties measured in the laboratory and those of the soil *in situ*, have led to the fourth phase—a more extensive use of field tests and their correlation with laboratory tests. Field tests are, of course, by no means new; for example, all engineers are familiar with loading tests to determine the bearing capacity of soil. Modern knowledge of soil mechanics, however, enables the engineer to interpret more correctly the results of such tests and to realise the limits of their validity.

The later phases should be regarded as supplementing rather than superseding the methods of the earlier phases. For example, empirical methods are still necessary for certain problems, but can now be applied with due regard to their limitations; even the classical earth-pressure theories still have their uses. The classification and identification of soils provide valuable information to supplement other data.

Reviewing the rapid development of soil mechanics, it is seen that a vast amount of knowledge, theoretical and practical, has been accumulated in a comparatively short period of time. If this knowledge is to be used to the best advantage in civil engineering, careful study must be made of "case histories," that is, observations of engineering works during construction and while in ordinary use. Also, every opportunity should be taken of investigating thoroughly any failures which are attributable to the soil. It cannot be too strongly emphasised that soil mechanics is not, and never can be, an exact science, and that its successful application always calls for experience and common sense.

CLASSICAL MECHANICS APPLIED TO SOILS

The first division of soil mechanics includes the conditions of stability of masses of soil, the determination of the internal stresses set up in soil under the action of external and gravitational forces and the laws governing the movement of water in soil. As with other engineering materials, the solution of stability and stress-distribution problems in soil involve the application of statics combined with assumptions as to deformation characteristics such as elasticity or plasticity.

The subject of earth pressure on retaining walls is probably the oldest part of theoretical soil mechanics. Of the classical theories one method of approach, that of Rankine published in 1856, is based on the assumption of an elastic material for which the shear resistance is dependent on intergranular friction. In the other method, the wedge theory, first put forward by Coulomb in 1771, a slip surface is assumed and the equilibrium of a mass of soil tending to slip is investigated by statics. By trying several different slip surfaces the worst case is found. This technique of trial slip surfaces is used extensively in investigating the stability of cuttings and embankments, but various simplifying assumptions have to be made to make the solution possible.

For foundations, in addition to the investigation of stability of the foundation as a whole, the distribution of pressure beneath the loaded area has to be found. For this purpose an elastic homogeneous material is usually assumed. Though this assumption is by no means correct, the results are considered near enough for practical purposes.

The study of movement of water through soil is essential for all problems relating to drainage. It is of special importance in connection with the design of dams, for which not only the rate of seepage but also the forces set up and their influence on stability must be considered. The question of movement of water also arises in the theory of consolidation of compressible soils under the action of pressure, which is an important factor in estimating the settlement of structures.

SITE INVESTIGATION

The next division of soil mechanics is concerned with the determination of the engineering properties of soils, and therefore includes site investigation, field testing, sampling and laboratory testing. Site investigation is a necessary preliminary to any engineering project, the object being to obtain information about the nature and properties of the various types of

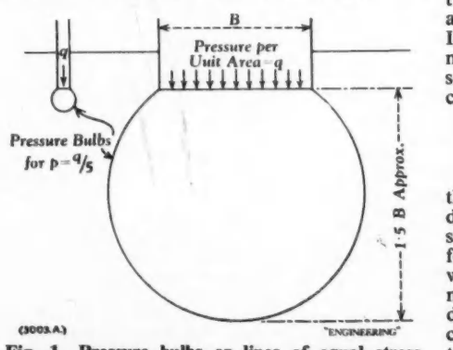

Fig. 1 Pressure bulbs or lines of equal stress through the soil mass below a structure.

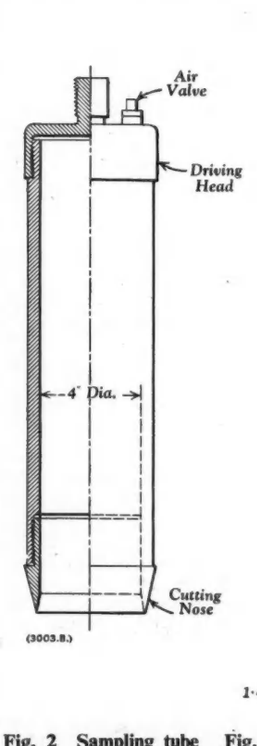

Fig. 2 Sampling tube for obtaining soil specimens from boreholes. The nose and cap can be replaced by solid caps.

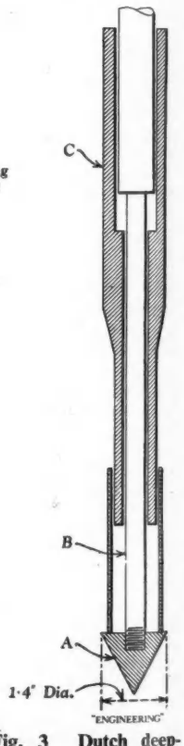

Fig. 3 Dutch deep-sounding apparatus for determining the point bearing resistance and the frictional resistance of soils.

* Paper, "The Fundamentals of Soil Mechanics," read at a joint meeting of Section C (Geology) and G (Engineering) of the British Association at Bristol on Monday, September 5, 1955.

† Senior Lecturer, Department of Civil and Municipal Engineering, University College, London.

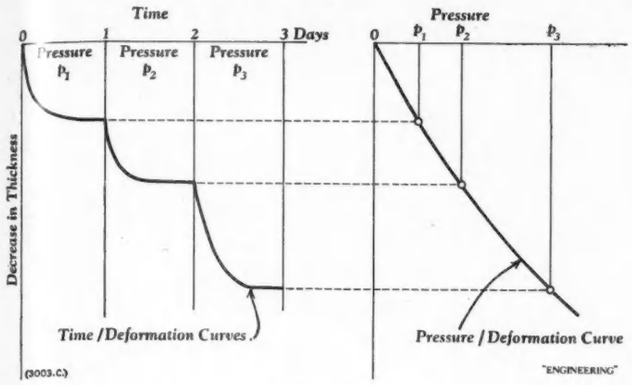

Fig. 4 Consolidation curves determined in an oedometer test. Coefficients of compressibility and consolidation can be derived that enable estimates to be made of the settlement that will occur under load.

soil in the region likely to be affected by the proposed work. The scale of the investigation obviously depends on the magnitude and importance of the project. While as a general rule it may be said that money expended on site investigation is money well spent, the question of economics must not be overlooked.

In deciding upon the depth to which the investigation should be carried, detailed information from geological survey organisations, which exist in most countries, is very useful. The chief point is to estimate the depth of soil which will be appreciably affected by the applied loads, and this depends upon the extent of the loaded area. The concept of the bulb of pressure, Fig. 1, illustrates this principle. It will be seen that at a depth of $1\frac{1}{2}$ times the breadth of the foundation the increase of pressure is approximately one-fifth of the contact pressure of the soil immediately under the base of the structure. For road construction, since the loads are applied on comparatively small areas, it is generally only necessary to go down a few feet below the formation.

For shallow investigations the excavation of test pits is the most satisfactory method; the soil can be examined visually and samples are easily taken for testing. For depths more than a few feet timbering is usually necessary and groundwater may be encountered, hence the use of boreholes becomes more economical.[2] In soft soils the hand-operated post-hole auger can be used for depths up to 20 ft. For greater depths well-boring appratus is required. Samples of loose material brought up from the boreholes at various depths are used for identification and classification, and in cohesive soil undisturbed samples are taken by forcing in a thin-walled tube with a detachable cutting edge. Fig. 2 shows a section through a typical sampling tube, 18 in. long and 4 in. internal diameter. The tube with its contents is withdrawn from the hole, the cutting nose and driving cap are replaced by solid caps, and the sample is ready for conveyance to the laboratory. When required for testing the soil sample is extruded from the tube by means of a screw jack, and specimens are cut from it for the various tests required.

For shear strength tests in the unconfined and triaxial compression apparatus smaller sampling tubes, 6 in. long by $1\frac{1}{2}$ in. internal diameter are used from which the test specimens, 3 in. long, are cut. Even though the walls are made as thin as possible for adequate strength, the volume of soil displaced is quite appreciable. This fact, as well as the friction produced during driving and the subsequent ejection of the sample, means that the soil cannot be entirely undisturbed. By using well-designed sampling tubes with clean and well-greased surfaces and with careful handling the disturbance can be reduced to a minimum, and except for certain types of "sensitive" clay, which will be referred to later, the normal method of sampling appears to be satisfactory. The provision of undisturbed samples of sandy soil, with little or no cohesion, presents considerable difficulty, but some ingenious devices have been made which extract samples with a minimum of disturbance to the soil structure.

Penetration tests are sometimes used to assess the variation in soil properties with depth. A penetration test does not give a direct measure of soil properties such as the shear strength or compressibility, for the penetration resistance is probably a function of both. By correlation with direct tests, however, comparative data can be obtained. An example of a static penetration test is the Dutch deep sounding apparatus, Fig. 3. This consists of a cone A at the end of a rod B which is guided in a steel tube C. The tube is forced into the soil by means of a jack, carrying with it the cone; then the cone is pushed down ahead of the tube. The resistance is indicated by the load on the jack. The resistance of the soil to penetration by the cone alone and that of the tube and cone together are measured, and thus the point bearing resistance and the frictional resistance can be separated. In this way the bearing capacity of piles driven to various depths can be estimated. This method is used extensively in Holland and Belgium, where conditions are particularly suitable. In other forms of penetration test the dynamic resistance is measured, for example, the number of blows of a specified magnitude required to cause a certain penetration. The results of such penetration tests must obviously be applied empirically.

CLASSIFICATION OF SOILS

The identification and classification of soils is very useful for giving a general indication of the properties to be expected. Typical classification systems used by engineers are the "General basis for field identification and classification of soils" and the "Soil classification for roads and airfields" published in the Code of Practice "Site Investigations."[3] Both these systems are based chiefly on the predominant particle size, and soils are broadly divided into three groups: (*a*) coarse-grained or cohesionless soils (gravels and sands); (*b*) fine-grained or cohesive soils (silts and clays); and (*c*) organic soils (peats). The identification of a sample of soil is effected by analysis of the distribution of particle size, supplemented in the case of cohesive soils by the determination of the liquid and plastic limits.[4] Down to the lower limit of fine sand (retained on a sieve with 200 meshes to the inch) the particle size analysis is obtained by sieving; for finer particles a sedimentation process is used.

The liquid limit is, in principle, the water content, expressed as a percentage of the weight of solids, at which the soil changes from a liquid to a plastic solid. In practice the liquid limit is given a more precise but empirical definition. A standard piece of apparatus is used, with a brass dish containing a cake of wet soil in which a V-shaped groove is cut. By means of a handle and a cam the dish is raised 1 cm. and allowed to fall freely on to a block of hard rubber. The liquid limit is defined as the water content at which 25 taps will just close the groove. The plastic limit is the water content below which the soil ceases to be plastic. It is found by rolling out a thread of soil on a glass plate, the plastic limit being attained when the thread just begins to crumble when rolled to a diameter of $\frac{1}{8}$ in. The difference between the liquid and plastic limits is known as the plasticity index. In addition to their use in the classification of fine-grained soils, the liquid limit and plasticity index give some indication of other properties.

ENGINEERING PROPERTIES

The most important soil properties from the engineer's point of view are compressibility, shear strength and permeability. The compressibility of soil, in the broadest sense of the word, may be defined as the relation between compressive deformation and the pressure producing it. The deformation is made up of one or more of the following: elastic deformation, recoverable when the pressure is removed; plastic deformation, due to plastic flow of material; and consolidation, or the closer packing of the particles resulting from the expulsion of water. In clay soils the settlement due to consolidation may be of considerable magnitude, but is a very gradual process.

The consolidation properties of soils are determined by oedometer test in which an undisturbed sample, usually 3 in. in diameter and $\frac{3}{4}$ in. thick, is compressed between two porous discs. The compressive load at first induces pressure in the water contained in the pores. This pressure sets up flow, and as the water escapes, the soil particles pack closer together and the thickness of the sample decreases. During this process the load is gradually transferred to the particles so that the intergranular pressure increases and the water pressure decreases. The rate of consolidation therefore falls off, and eventually equilibrium is reached when all the external load is carried by intergranular pressure. Fig. 4 shows the effect of successive increments of pressure on the compressive deformation of the soil sample. From the results of the consolidation tests coefficients of compressibility and consolidation are derived from which the magnitude of the settlement of a structure and the time in which this will develop can be predicted. Other well-known phenomena closely related to the property of compressibility are the swelling and shrinking of some types of soil with changes of water content, natural or otherwise. Mention should also be made of artificial compaction of the soil by rolling or tamping. Here the contraction in volume is effected mainly by a reduction in the air voids.

The shear strength of soil is assumed to be made up of two components: intergranular friction and cohesion. Generally speaking, sands and gravels derive their strength almost entirely from friction, while in clay soils cohesion predominates. The shear strength of soils may be measured directly in the shear box, shown diagrammatically in Fig. 5. The soil sample is contained in a square box split centrally on a horizontal plane. A gradually increasing horizontal load is applied to the upper half of the box until shear failure takes place. By testing several similar samples with different compressive loads, thus varying the frictional resistance, the effects of cohesion and friction can be separated. In Fig. 6 the relation between shear strength and normal pressure is shown for three types of soil.

The shear strength of soil is measured directly in the shear box, but it is more usual to determine this property indirectly from a compression test. The unconfined compression test, suitable only for clay soils, is carried out in the field using a portable machine. In this test

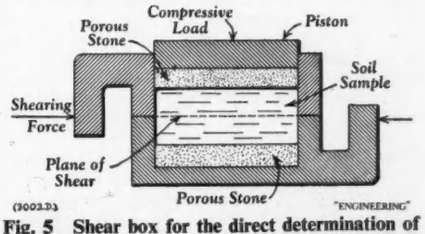

Fig. 5 Shear box for the direct determination of the shear strength of soils. The contribution of internal friction is found by varying the applied compressive stress under which the test is made.

an undisturbed specimen, 1½ in. diameter and 3 in. long, is extracted from an excavation or a borehole and tested in simple axial compression. The triaxial compression test can be used for almost any type of soil. In this the specimen, protected by a thin rubber sleeve, is enclosed in a cell where it is subjected to uniform water pressure, while the compressive axial load is gradually increased till failure occurs. With the application of lateral pressure the conditions of the test conform more closely to those of the soil in its natural state.

The reduction in the shear strength of clay soil caused by remoulding is known as "sensitivity." Over-consolidated clays which show little or no loss of strength when remoulded are termed "insensitive." Most other clay soils show some degree of sensitivity. For very sensitive clays even slight disturbance during sampling may have considerable effect on the strength. For such soils the ordinary methods of testing are unreliable, and the vane test[5] is more suitable. This is an *in situ* test, in which a cruciform vane is pushed into undisturbed soil. The torque required to rotate the vane and the enclosed soil is recorded, giving a measure of the ultimate shearing resistance.

In clay soils the results of a shear test are considerably affected by the conditions of testing, for example, whether or not consolidation, with consequent reduction in water content, can occur during the test. The tests are therefore carried out either as undrained or "quick" tests, or as drained or "slow" tests. The type of test to be used is chosen so as to imitate as closely as possible the conditions which are expected to apply in the field. In undrained tests on cohesive soils it is sometimes useful to measure the pore-water pressures set up during the test.

The permeability of soil is the property which governs the flow of water in the voids under the action of a hydraulic head. It is of great importance to engineers in connection with water supply, drainage, consolidation of clay deposits, and all problems involving the movement of water in the soil. The permeability of soil can be measured in the laboratory, but the difficulty of testing the soil in the same condition as it exists in the ground makes the results of limited value. More reliable estimates of permeability can be made from observation of groundwater level in the vicinity of a well from which water is being pumped at a steady rate, provided that the soil is fairly uniform.

APPLICATIONS OF SOIL MECHANICS

The third division of soil mechanics comprises the application to civil engineering design and construction. Little need be said here, since subsequent papers* being given at this Session describe the use of soil mechanics in foundation design and in some of the problems arising in railway engineering. Brief mention must, however, be made of a very important application not included in these papers, namely, the design and construction of roads and airfield runways. Experience with ever-increasing wheel loads has shown that improved designs of pavement and surfacing are of no avail unless the subgrade soil is capable of resisting the stresses induced without excessive deformation. The study of the pressure distribution in the subgrade soil and of the relevant soil properties is essential if economic, but effective, pavement design is to be achieved. In addition, much attention has been paid to the improvement of the qualities of natural soil by drainage, compaction and stabilisation. The latter can be effected by suitable mixing of different types of soil, or by the addition of small quantities of cement, bitumen or other stabilising agent.

RELATION OF SOIL MECHANICS TO GEOLOGY

It has always been customary for the civil engineer to consult and co-operate with the geologist about mining operations, and also on water supply and storage for municipal services and hydro-electric schemes. It is now being realised that knowledge of geology on the part of the engineer himself, as well as the professional assistance of the geologist, can be helpful in almost any work involving soil mechanics. In particular, three instances of such co-operation may be mentioned: (i) the planning of site investigations; (ii) the study of landslides, slips and coast erosion; and (iii) the study of the engineering properties of silt and clay deposits in relation to their mode of origin and their geological history.

* These papers will be published in future issues of ENGINEERING.

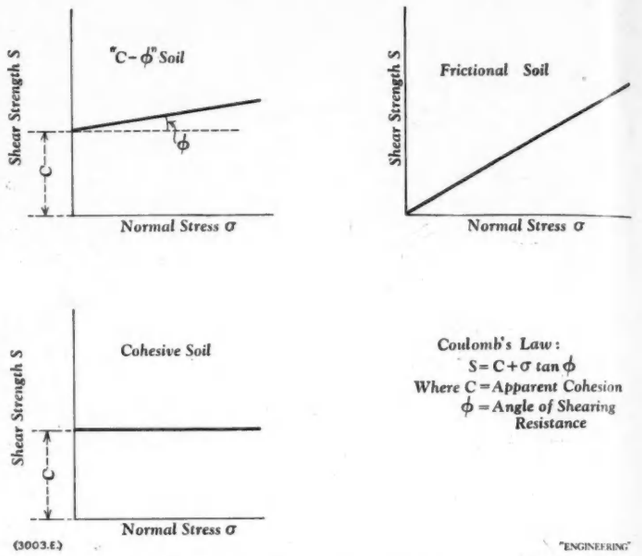

Fig. 6 Relation between shear strength and normal pressure in different soil types. Most natural soils exhibit both friction and cohesion in shear tests, giving rise to characteristics as shown in the top left-hand figure.

In site investigations geological information is essential for the efficient planning of the work. Such knowledge assists the engineer in deciding upon the number, spacing and depth of boreholes, and in his interpretation of the data obtained from them. In addition to accurate information about the composition and properties of the soil and rock affected by an engineering project, knowledge of the geological structure is of the greatest importance. The existence of faults, steep dips, folds and other irregularities in the strata will generally be shown on geological maps or may be observed on the site. Frequently, especially in valleys, a deposit of alluvium or drift may conceal faults, fissures and dislocations in the original valley floor. Instances have been recorded of isolated boulders being mistaken for bedrock, and of widely spaced boreholes failing to reveal an irregularity such as an old river channel in an apparently level bedrock surface. The geological survey cannot be expected to show details of such features, but an appreciation of the geological structure of the site will warn the engineer to exercise special care in his investigations.

In recent years researches have been carried out to establish some measure of correlation between the engineering properties of fine-grained soil deposits with their geological characteristics. It has been established that the predominant minerals in a clay soil, such as quartz, muscovite, kaolinite, illite and montmorillonite, have a marked influence on its plasticity. Other factors which affect the properties of deposits are the mode of origin—wind-borne, glacier-transported, or deposited in fresh or salt water—and the subsequent history such as consolidation by overlying deposits which have sometimes been partially eroded later, and the leaching out of soluble salts.

Here again, while such geological data, when available, are of the greatest help to soil mechanics, tests such as those for the liquid and plastic limits, shearing strength and compressibility can be of value to the geologist in studying the geological history of soils. For example, from consolidation tests on pre-consolidated clay the shape of the pressure/deformation curve gives a good indication of the maximum pre-consolidation pressure, from which an estimate can be made of the depth of material which at one time existed above the clay.

A brief reference should also be made to the use of geophysical methods in soil exploration for civil engineering purposes.[6] The methods available are the electrical resistivity and the seismic refraction methods. It is claimed that the data obtained from a geophysical survey using one or other of these methods are useful in providing a basis for the drilling and testing programme from which the necessary detailed information will be obtained. Considerable experience is required in interpreting the results from geophysical exploration.

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TELEVISION TRANSMISSION FROM HELICOPTERS

Value of a Hovering Camera

Air-to-ground television transmission from a helicopter has been successfully undertaken at Filton by the Bristol Aeroplane Company, Limited, in collaboration with Pye Limited, Cambridge. The helicopter, a Bristol Sycamore, with a Pye television camera mounted in its doorway, flew at heights of up to 500 ft. transmitting pictures of the Bristol factory and of the countryside to a screen on the ground.

For ease of loading and unloading, the camera and transmitting equipment were mounted on a stretcher normally carried when the aircraft is engaged on ambulance duties. To remove the complete unit it was thus necessary only to disconnect the aerial and unload the stretcher.

There are numerous applications for which the helicopter provides a more satisfactory television vehicle than fixed-wing aircraft. Its ability to hover at the most suitable height over any given spot, is valuable not only for commercial outside broadcasts but also for traffic control, civil defence reconnaissance over bombed areas, survey of flood damage, etc. In the military field a helicopter-borne camera could enable formation commanders to watch operations in progress.

ENGINEERING, MARINE AND WELDING EXHIBITION

AND THE FOUNDRY TRADES EXHIBITION OLYMPIA, LONDON SEPTEMBER 1—15

Third Article

This year's exhibition was declared open by Mr. H. S. Broom, the President, who made the announcement over the broadcast system and so dispensed with formal platform speeches. He referred to the many technical developments that had taken place in the two years since the last exhibition, in particular to those which were typified by Geneva.

In this article we continue our description of some of the items displayed.

POSITIVE-DISPLACEMENT ROTARY COMPRESSOR

On view on the stand of James Howden and Company, Limited, 195 Scotland-street, Glasgow, C.5, is a compressor with cut-away casing to show the mechanism of the Howden compressor, which is a development of the Lysholm compressor for which they have sole manufacturing rights in Great Britain, and world selling rights. Such a compressor is illustrated in Fig. 38, below.

The Howden compressor is a lobe-type positive-displacement high-speed rotary machine having no reciprocating parts. It has all the advantages inherent in these features, i.e., stable pressure-volume characteristics, freedom from vibration, small size and low weight. Its robust design ensures a high degree of reliability and a minimum of maintenance.

Lobe-type machines, as typified by the Root's-type blower before the introduction of the Lysholm compressor, have been fluid transporters rather than compressors, that is, the air is transported from the inlet to the outlet at constant volume, and the pressure rise is obtained by virtue of back flow, from the high-pressure outlet duct, of some of the gas already compressed, into the constant volume zone of the compressor. Until the advent of the Lysholm compressor, the lobe-type gas compressor was limited to low-pressure-rise installations. At pressure ratios above about 1·3 to 1 the efficiency falls and the higher the pressure ratio, the more adverse is the effect on efficiency.

The working parts of the Howden compressor, that is, the parts which come into contact with the gas and compress it, comprise two helically lobed intermeshing rotors which rotate within a closely-fitting main casing bored out in the form of two intersecting parallel cylinders. The main casing is closed at one end by a cover containing the inlet port and at the other end by a cover containing the discharge port. As the rotors revolve and the lobes unmesh, air or gas is drawn in, filling the spaces between the lobes and the main casing, and is carried down the casing until remeshing of the lobes compresses the air or gas and finally discharges it through the outlet port.

The rotor form is arranged so that gas, during the compression period, is sealed in the inter-lobe space and is not in communication with any other lobe space or with the inlet or outlet. By rotation and intermeshing of the rotors the sealed gas is compressed to give the required delivery pressure so that under design conditions, on release to the outlet, there is no back flow of gas into the lobe space. Thus, whereas in the Root's-type blower the pressure rises at constant volume, in the Howden compressor the compression approaches an adiabatic process. The adiabatic compression before release effects a large saving of power at high-pressure ratios over the constant-volume compressor, and consequently gives the Howden compressor a higher efficiency than the Root's-type blower.

The rotors and casings are accurately machined to provide a fine running clearance between the meshing lobes, between the tips of the lobes and the main casing, and between the end faces of the rotors and the end covers. No lubrication is therefore necessary in the working space and consequently the delivery from the compressor is uncontaminated by oil.

The rotors are maintained in their correct angular relationship by synchronising gears which are set during assembly. Only about 5 per cent. of the total input power is transmitted through the synchronising gears to the mating rotor, nearly all the power being transmitted to this rotor by the air or gas being compressed.

In the smaller machines of the standard range the rotors are integral with their shafts, which run in plain journal bearings in the end covers of the compression chamber. In the larger machines, stub shafts are fitted to the rotors and the bearings are outboard of the end covers.

The journal bearings for the rotor shafts are of the shell type, steel backed with white-metal linings. The axial thrust due to compression is absorbed by tilting-pad thrust bearings. Oil throwers prevent lubricating oil travelling along the shaft to the specially developed compression-space seals in the inlet end cover of the compressor which prevent ingress of atmospheric air to the working space. In the discharge-end cover similar seals prevent leakage of the compressor working substance to atmosphere.

Four standard sizes of compressors are produced, having rotor diameters of 125 mm., 200 mm., 10·5 in. and 16·5 in. This range covers capacities from 400 cub. ft. per minute to 8,500 cub. ft. per minute, with discharge pressures up to 60 lb. per square inch gauge in one stage, higher pressures being obtained by using two or more compressors in series. As a vacuum pump with atmospheric discharge, a single machine is suitable for inlet pressures down to 4 lb. per square inch absolute (22 in. Hg. vacuum).

The standard Howden compressors are suitable for handling air and other non-corrosive gases or vapours. For corrosive gases or vapours, special materials can be employed. Since there is no internal lubrication, and since running clearances exist in the compression space, Howden compressors are particularly suitable for duty in dust-laden atmospheres. Inlet and outlet silencers have been developed to reduce noise to normal engine-room level.

The machine on view at Olympia, illustrated in Fig. 38, is a 200-mm. compressor with a capacity of from 800 to 2,000 cub. ft. per minute of free air corresponding to rotor speeds of approximately 5,000 and 11,000 r.p.m., respectively. The 200-mm. compressor is normally fitted with a speed-increasing gearbox so that it can be driven by a two-pole or a four-pole electric motor, or by a high-speed Diesel engine. For a steam or gas-turbine drive the compressor can be directly coupled without the gearbox. Quarter-scale wooden models typify compressor sets with these drives.

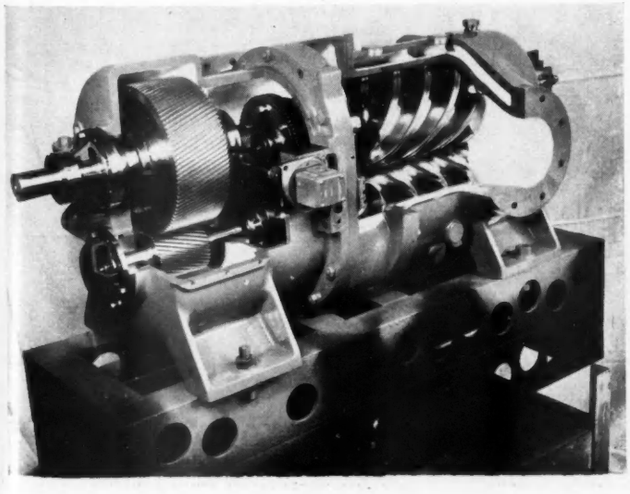


Fig. 38 Lobe-type positive - displacement high-speed rotary compressor, which works on a near-adiabatic cycle. James Howden & Co., Ltd.

BREATHING APPARATUS FOR SHIPS

A new self-contained compressed-air breathing apparatus for use in ships, for fire-fighting, etc., which has recently been approved by the Ministry of Transport and Civil Aviation, is displayed on the stand of Siebe, Gorman and Company, Limited, Neptune Works, Davis Road, Chessington, Surrey. This apparatus has now been supplied to all the leading shipping lines, to the Fire-Fighting School at Liverpool for training deck and engineer officers of the Merchant Navy, and to H.M.S. Phoenix, the Royal Navy Fire-Fighting and Damage Control Training Establishment.

The apparatus is similar to the Siebe Gorman Mark II apparatus which is used extensively by fire brigades and in industry; i.e., it is of the open-circuit type with a capacity of 1,200 litres of atmospheric air compressed to 120 atmospheres, and operates on a two-stage pressure reducing system, but it is modified slightly to meet the special conditions of ships at sea. To enable a man negotiating a small aperture to push the bulk of his apparatus through to the other side while still retaining his face mask and breathing from the cylinder, a longer breathing tube is fitted. Two spare cylinders, a pressure gauge, and a compact storage box are provided with the equipment. Other apparatus displayed for

Exhibits Described

Positive-Displacement Rotary Compressor *James Howden and Co., Ltd.*
Breathing Apparatus for Ships *Siebe, Gorman and Co., Ltd.*
Viscous Fluid Pump *Varley Pumps and Engineering Ltd.*
Oil and Water Coolers *Serck Radiators, Ltd.*
Hot-Water Circulator *Sealed Motor Construction Co., Ltd.*
Automatic Production of Sand Moulds *Pneulec Ltd.*
Automatic Metal-Wire Spraying Installation *The Metallizing Equipment Co., Ltd.*
Smoke Density Indicator *Ronald Trist and Co., Ltd.*

Fig. 39 Paddle displacement pump for viscous fluids. Varley Pumps & Engineering, Ltd.

use on ships includes the Spirelmo smoke helmet with air bellows, the Bloman hose mask equipped with a hand-operated fresh-air blower, and the Antipoys short-distance fresh-air breathing apparatus of the type used by fishermen in trawlers.

Siebe, Gorman are also showing a range of industrial safety equipment including self-contained breathing apparatus, gas masks, dust masks, welders' helmets and handshields, etc.; and are demonstrating underwater equipment, such as the Essjee Aqualung, standard helmet diving apparatus, and underwater cutting equipment, in a glass-windowed diving tank.

VISCOUS FLUID PUMP

The paddle displacement pump, which is being shown by Varley Pumps and Engineering, Limited, Ferry-lane, Brentford, Middlesex, and is illustrated in Fig. 39, has been designed for pumping fluids of high viscosity such as printing inks, paints and varnishes, which may also be pigmented or have some solid matter in suspension.

Displacement is effected by two paddles, which are mounted on separate shafts and are accurately located at 90 deg. to one another. These paddles are driven and timed through external gearing which is case-hardened and ground and is out of contact with the liquid. As they are not under mechanical load to one another, wear is reduced to a minimum.

Seals are fitted to the shafts on either side of the driving gears and, in addition, there is a central chamber filled with heavy grease to prevent leakage from the actual pump body. The shafts are supported in " wrapped " bushes which are easily replaceable. The body and end covers are of cast iron, the shafts are of steel and the paddles of bronze or cast iron.

When handling spirit or low-viscosity oil the output of the pump is 60 gallons per minute at a speed of 960 r.p.m. and a maximum working pressure of 100 lb. per square inch. The speed can be varied down to 100 r.p.m. according to the consistency of the material.

OIL AND WATER COOLERS

Serck Radiators, Limited, Warwick-road, Birmingham, 11, are exibiting a range of radiators and other heat-exchange equipment including units for stationary and marine Diesel engines, gas turbines, atomic energy plant, and oil refineries. Some of the larger equipment, including a bled-steam air heater for marine propulsion plant, will be represented by models or photographs. Among the other equipment on show is a fuel-cooled oil cooler, of light alloy construction, designed for use with a gas turbine and capable of dealing with kerosine/lubricating oil differentials such as 2,000/100 lb per square inch.

A new combined water and oil cooler for internal combustion engines is also being exhibited and is illustrated in Fig. 40.

Known as the " W " type, it is available at present to suit engines from about 100 to 450 h.p. of both land and marine types. Engine jacket cooling is by fresh water, which is re-circulated from a small header tank incorporated in the cooler, and this water is also used to cool the engine oil. Cooling of the jacket water is by means of raw water which is from the sea in the case of marine installations or from any convenient source for land engines. The raw water enters at the top of the unit and is circulated by means of baffle-plates round the outsides of a stack of tubes through which the jacket water passes. The flow of the raw water may be single or double according to the circumstances in a particular installation. From the outsides of the tubes in the upper element the jacket water passes to the lower heat-exchanger, where it goes through a stack of tubes while the engine oil is circulated on the outsides of the tubes by a series of baffle-plates similar in design to those on the upper stack.

A thermostatic valve is incorporated in the jacket-water flow, and when the engine is cold this valve by-passes the water from the upper heat-exchanger. The jacket water thus heats up quickly, and on passing through the lower heat-exchanger heats the engine oil. A cold engine can therefore be brought up to normal working temperature at high speed, and full power output is available quickly so obviating the possibility of excessive wear. On reaching working temperature the thermostat opens, and the normal flow of the jacket water, first through the upper chamber and then through the lower, commences.

A pressure filling-cap which incorporates a vacuum-release is fitted to the header tank, and it is thus possible for the unit to be pressurised and run at high temperatures without danger of boiling or spillage of the jacket water. The header tank is an aluminium casting, the water boxes are of cast iron or gunmetal, and the tubes are aluminium-brass. The various parts of the unit handling jacket water, raw water for cooling and oil are subjected to pressure tests during manufacture, according to the duties for which they are designed.

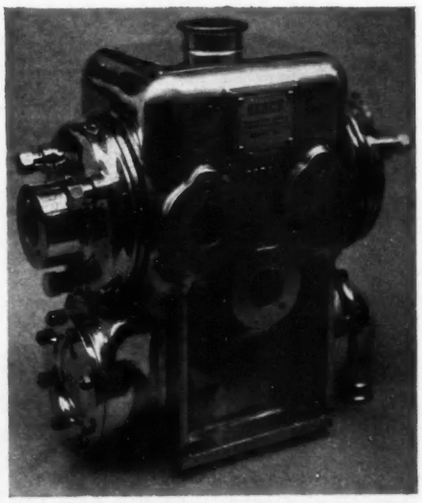


Fig. 40 The Serck combined jacket-water and oil cooler incorporates a thermostatic valve for by-passing the jacket cooler and using the hot jacket water to heat the oil quickly on starting from cold. Serck Radiators, Ltd.

HOT-WATER CIRCULATOR

The pump, which is illustrated in Fig. 41, and is being shown by the Sealed Motor Construction Company, Limited, Bristol-road, Bridgwater, Somerset, has been designed as a hot-water accelerator in central heating systems and for that reason its noise level has received special consideration.

For instance, the motor has been built to produce the minimum of magnetic hum within the limits of economic design; and the hydraulic part has been constructed to reduce noise as far as possible. The rotating assembly is carefully balanced dynamically and as a further precaution against the transmission of vibration the pump flanges are bonded to the casing through resilient rubber rings.

The pump casing can be constructed either of cast-iron or a corrosion-resistant bronze. The impeller is of the latter material and integral with it is a sleeve for protecting the motor shaft. Leakage is prevented by a mechanical seal and as a further precaution a rubber slinger is fitted on the shaft between this seal and the motor. The stator can be removed without disturbing the piping or circulation through the pump.

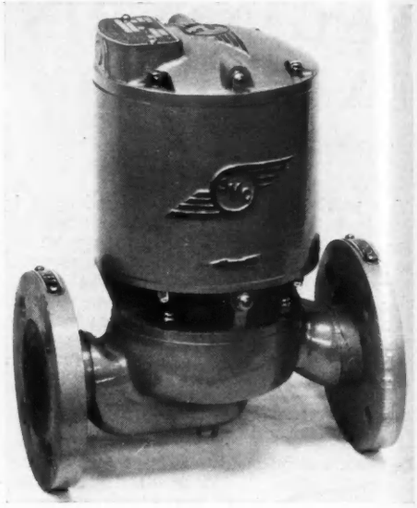


Fig. 41 Hot-water accelerating pump for central heating systems. Sealed Motor Construction Co., Ltd.

The accelerator is made in six sizes with outputs from 14 to 26·5 gallons per minute against frictional heads of 12 to 2 ft. Power is obtained from either a 200/250-volt single-phase or 380-440-volt three-phase motor.

AUTOMATIC PRODUCTION OF SAND MOULDS

The principal exhibit on the stand of Pneulec, Limited, Mafeking-road, Smethwick, Birmingham, is the " Stationmaster " automatic jar-squeeze-strip moulding machine, which is being shown for the first time in this country. The machine is made in two sizes at present, to accommodate moulding boxes 30 in. wide by 36 in. long, or 42 in. wide by 48 in. long. It produces moulds by a series of mechanical operations, no manual work being involved. It is shown in Fig. 42.

The machine is of the two-station type, with an indexing mechanism to transfer the boxes from one station to the other. It can be arranged to produce one part of a mould only, as shown in the accompanying illustration, or it can be equipped with two pattern plates and two squeeze heads to produce the cope and drag of a mould alternately; it is shown in the latter form at the exhibition. Empty boxes are supplied to the machine by a conveyor which is an integral part of it, and is also used to discharge the moulds. A sand measuring hopper (which is not shown in the illustration) is also incorporated, and it is only necessary to provide a source of moulding sand for the hopper, and suitable conveyors leading to and from the machine. A control cabinet is provided, with a two-position switch for setting the machine to automatic operation or manual control; the latter is used only when setting the machine up. With the switch in the " manual " position the operations required to complete the cycle are individually controlled by a series of push-buttons. When the setting has been done, the machine is switched to automatic control, and on the completion of each operation in the cycle, limit switches initiate the next operation automatically.

Empty boxes arriving on the conveyor are brought to rest by a stop and are lowered automatically, one at a time, on to an indexing turret. This takes them through 180 deg. to the jolt and squeeze station, at the same time

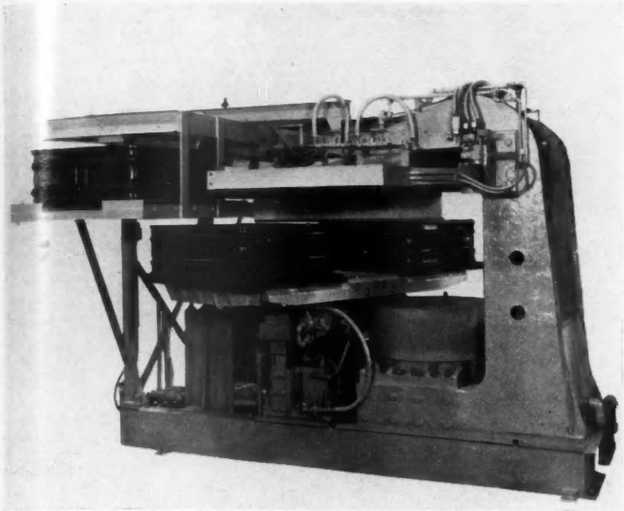


Fig. 42 The "Stationmaster" moulding machine produces moulds in an automatic cycle. The machine is shown indexing round to transfer an empty box to the jolt and squeeze station. Pneulec Ltd.

bringing back the mould which has just been made. This is stripped from the pattern, elevated to the discharge conveyor and sent off for closing. An empty box is then lowered into place ready for transfer to the jolt and squeeze station.

The full cycle of operations is as follows: at the jolt and squeeze station sand is allowed to enter the measuring hopper, which is lowered over the box. The hopper gates open, the box is filled with the correct quantity of sand from the hopper, and the gates close when the hopper rises again. Jolting then proceeds. The next operation is to strike off the sand and squeeze the box. To do this the squeeze head advances until it is over the box, which is raised and squeezed by the squeeze cylinder which is coaxial with the jolt cylinder. The squeeze piston is of large diameter, giving a squeeze of approximately 65 lb. per square inch. If only one part of a mould is being made, there is only one squeeze head, but if two parts of the mould are being produced as on the machine at the exhibition, there are two squeeze heads, which shuttle in and out alternately, to suit the particular pattern plate which is at the jolt and squeeze station. At the conclusion of the squeezing operation the squeeze head retracts, and the mould is ready for stripping. To do this the turret rises and lifts the mould. It then indexes through 180 deg. to bring the mould over the stripper, and lowers it into position. At the same time the opposite arms on the turret bring an empty box to the station.

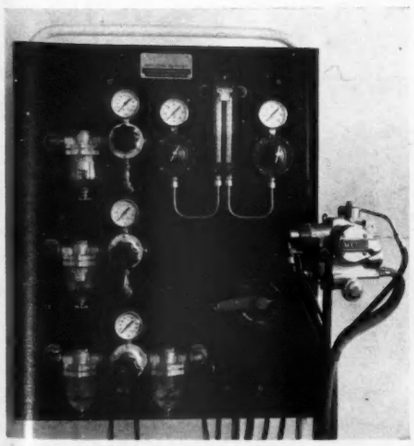


Fig. 43 Automatic metal-wire spraying installation for engineering components. The spraying gun is seen on the right adjoining the remote-control panel governing its ignition and operation. Metallizing Equipment Co., Ltd.

Simultaneously with the making of a mould at the jolt and squeeze station, the followin operations take place at the stripping station. The stripper rises to strip the mould off the pattern. Side rollers then lift the mould off the stripper ready for discharge on to the conveyor. A pin carried by an overhead pusher engages an empty box to locate it accurately, and pushes it forward to the stripper. This movement also pushes the mould away to the discharge conveyor. A compressed-air pattern blow-off operates at this point in the cycle. The side rollers then lower the empty box on to the stripper and a pattern-spray operates. The stripper is then lowered, the pin is retracted, and the box is on the turret arms ready for indexing to the jolt and squeeze station.

AUTOMATIC METAL-WIRE SPRAYING INSTALLATION

The Metallizing Equipment Company, Limited, Chobham, Woking, Surrey, are showing for the first time their fully-automatic metal spraying installation consisting of their Metco type 2Y gun seen on the right in Fig. 43 alongside the remote-control panel governing its operation.

It may be recalled, in the first place, that Metallizing is a process whereby a metal, in wire form, is automatically drawn through a spraying gun or pistol to a nozzle ,where it is melted in an oxygen-gas flame and "atomised" by a blast of compressed air which carries the metal particles on to a previously prepared surface. The particles "mesh" into one another on this surface to produce a coating of the sprayed metal which is intended for such purposes as the building up of worn parts or as a protection against corrosion. The gas used with the oxygen is normally acetylene or propane.

The principal features of the new installation, in addition to its remote-control operation, are air-valve operated "stop-start" wire-feed control; remote control ignition by means of a sparking plug; and an independent air supply to the fan spray air cap mounted on the nozzle of the gun, permitting remote control of the width of the metal spray so that a narrow band of metal or a very wide one can be deposited without any adjustment being made to the gun itself. The unit controlling the variable-width air cap is seen on the upper left-hand side of the control panel in Fig. 43. Below it is the air-control unit for the wire feed and below this is the air-control unit for the compressed-air blast to the spraying gun. On the upper right-hand corner of the panel is the gas-flow meter incorporating regulators for the oxygen and the fuel gas. The handle for the remote-control ignition and operation of the gun is seen in the lower right-hand corner of the panel.

The makers state that in recent months this fully-automatic spraying installation has been applied to many different purposes ranging from the zinc spraying of steel sections to the coating of exhaust-valve seats with aluminium. Various methods are adopted to accomplish the spraying operation and, in appropriate cases, the work is rotated in a lathe while the spray gun is traversed along the surface.

SMOKE DENSITY INDICATOR

A working model of the Electricon smoke density indicator is on view on the stand of Ronald Trist and Company, Limited, Bath-road, Slough, Buckinghamshire. In this instrument, which comprises projector and receiver optical units, a control unit, and an indicator unit, a beam of light is passed through the smoke stack or flue and is directed on to a photo-electric cell system, the amount of light falling on the photocells giving a measure of the smoke density. This is indicated on a 6 in. iron-clad moving-coil meter.

The light projector consists of a stout-filament projector lamp of small wattage, a lens, and a "reference" vacuum photocell. The receiver includes a lens to condense the received light

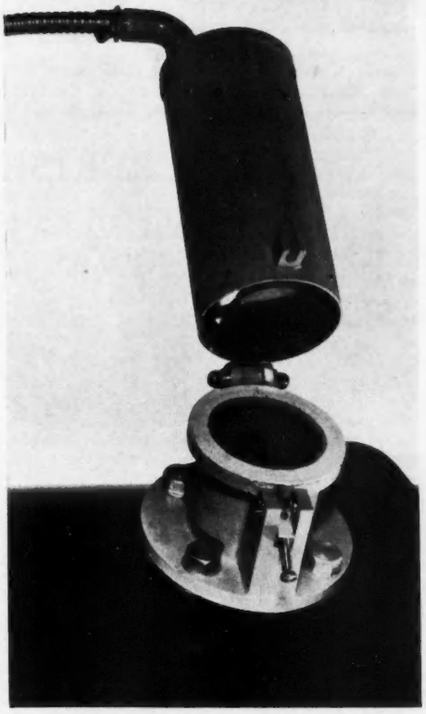


Fig. 44 The hinged optical units of the Electricon smoke density indicator. Ronald Trist & Co. Ltd.

beam and direct it to the photocells. Both projector and receiver optical units are enclosed in cylindrical casings, as shown in Fig. 44, hinged to flanged mountings to permit easy lens cleaning. The control unit provides stabilised supplies for the lamp, the photo-electric cells, a balanced valve circuit which amplifies the photocell output, and the amplifier and relays associated with an alarm circuit which provides for operating an alarm bell or other suitable warning device. The standard instrument operates on a 230-volt 50-cycle supply.

Also on view on the Trist company's stand are moulded-fabric and rubber packings and seals; steam-raising boiler equipment featuring the Thermofeed feed-water regulator and Hilo level-alarm equipment; and a range of Mobrey magnetic liquid-level control switches, available for working pressures up to 1,500 lb. per square inch and working temperatures up to 750 deg. C. The switches are shown operating in conjunction with Mobrey alarm panels giving both visual and audible warning of high and low level.

To be continued

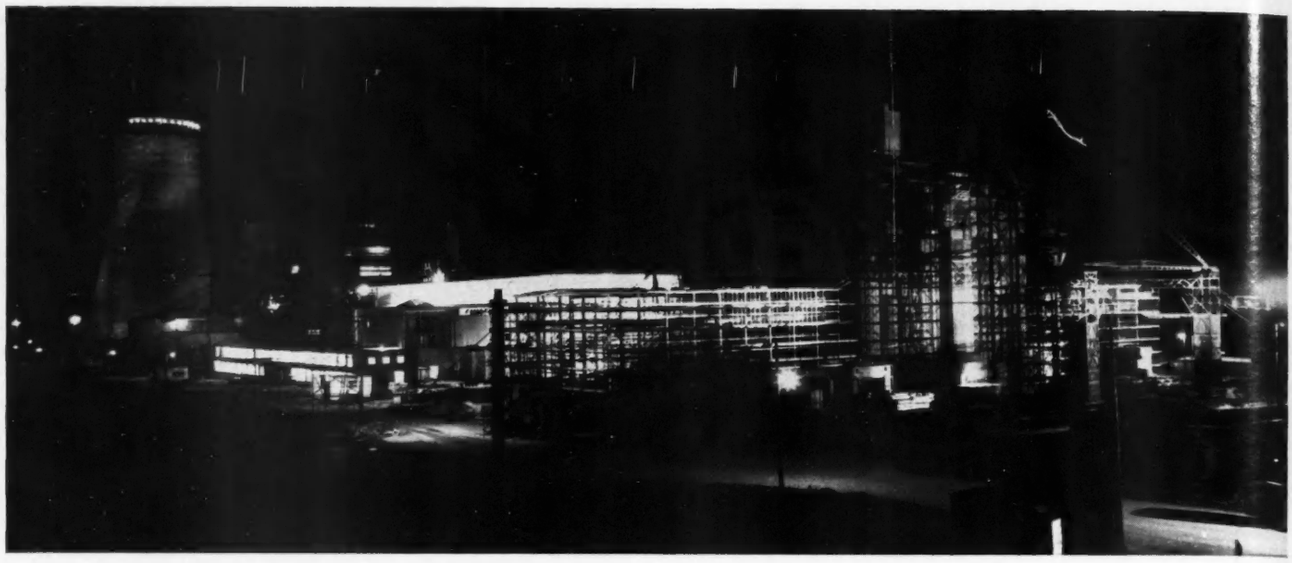


Fig. 1 Construction of Calder Hall atomic power station proceeding by night. The second reactor can be seen in the foreground with the turbine hall, while beyond are the first reactor and the first cooling tower. Taylor Woodrow, who are engaged on this work, are members of a group (with the English Electric Company and Babcock and Wilcox) formed to undertake atomic power projects involving gas-cooled graphite-moderated reactors.

ENTERPRISE AT GENEVA

ATOMIC ENERGY EXHIBITS BY BRITISH FIRMS

No small part of the praise lavished by visitors on the United Kingdom exhibits at the Geneva atomic energy fair may be attributed to the excellence of the British industrial stands which were on view in the Palais des Expositions. This exhibition was one of two held concurrently with the International Conference on the Peaceful Uses of Atomic Energy, and some 40 British firms took part. The official national displays in the Palais des Expositions and the exhibits shown in the Palais des Nations by the scientific delegations were described in ENGINEERING *last week (page* 299). *In this article, the first part of which is published below, we continue our description of items exhibited by British companies and deal mainly with those representing research and the construction and installation of atomic power stations; subsequently we hope to cover the contribution of the metallurgical and instrument industries. A previous article appeared on August* 5 *(page* 176).

PUMPING LIQUID METAL

In the United Kingdom a number of industrial groups have been formed with the object of exploiting the possibilities of atomic power production. One of these groups, representing an association between John Thompson Limited, and Associated Electrical Industries Limited, showed a variety of nuclear equipment including induction pumps for liquid metals, a new linear accelerator, control apparatus and examples of heat-exchanger work, and drawings and models of a water-moderated research reactor which is offered for sale.

The British Thomson-Houston Company, Limited, of Rugby, a member of this group, exhibited two models, one of an annular linear induction pump for liquid sodium, and the second of an alternating-current induction pump for such materials as bismuth. The use of liquid metals for cooling nuclear reactors is becoming increasingly important—the Dounreay reactor, for example, (ENGINEERING, August 26, page 280) will employ liquid sodium—and it has thus been necessary to devise means of pumping these materials without loss, since they are expensive, and without interaction between liquid metal and pump components. An electrical induction pump is the ideal solution since appropriate materials can be chosen for contact with the liquid metal, and since there are no seals or moving parts.

Among the items displayed by Metropolitan-Vickers Electrical Company, Limited, Trafford Park, Manchester, 17, were a model of a linear accelerator under construction for the United Kingdom Atomic Energy Authority, a complete reactor control-rod mechanism together with sub-assemblies, a mass spectrometer, and photographs of two linear accelerators, a 300-MeV synchrotron and a 400-MeV synchrocyclotron. The synchrotron, which has been built for sub-nuclear research, is installed at Glasgow University, the synchrocyclotron at Liverpool University, and one of the linear accelerators (8 MeV) at Hammersmith Hospital; the other, of 4-MeV rating, is a standard model.

LINEAR ACCELERATOR

The Metrovick MS2 mass spectrometer was shown with a recorder unit with automatic range changing, and its uses are: the determination of abundance ratios of static isotopes, the analysis of inorganic and organic gases or vapours, and investigating the products of ionisation and dissociation of molecules.

Fig. 2 shows the model of the Metrovick linear accelerator. It will serve as a neutron source for neutron time-of-flight spectroscopy and, as far as is known, will be more powerful than any yet built. It is designed to produce an average beam power of 30 kW at an energy of 25 MeV. There will be six sections each energised by a klystron amplifier operating at a wavelength of 10 cm. and at 6-MW peak power. It will be possible to set the output pulse length of the accelerator at several values between 0·2 and 2 microseconds and the recurrence rate at values between 25 and 750 pulses per second. Reference is made to this equipment in an article dealing generally with linear accelerators which appears on page 340 of this issue.

RESEARCH REACTOR FOR SALE

Perhaps the most interesting item in the exhibit contributed by John Thompson Limited, Ettingshall, Wolverhampton, was a model and drawings of a " swimming pool " research reactor which has been offered for sale. They also exhibited a chemical proportioning meter, a photograph of water treatment plant, and fabricated samples of stainless-steel heat exchanger parts, aluminium extrusions and butt welds, double-walled leakproof tube for heat exchangers and various other heat-exchanger

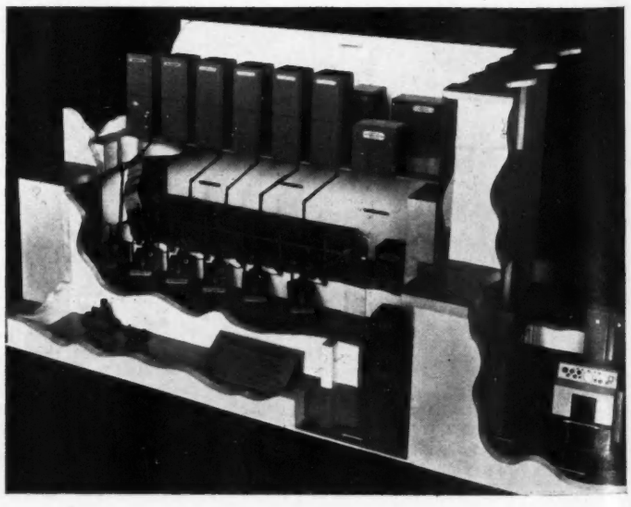


Fig. 2 Model of a Metrovick linear accelerator under construction for the United Kingdom Atomic Energy Authority. It will be used to provide a neutron source for neutron time-of-flight spectroscopy and is designed to produce an average beam power of 30 kW at an energy of 25 MeV.

equipment. John Thompson Limited are also to take part in the construction of the fast breeder reactor at Dounreay and will be responsible for the liquid-metal circuits, pressure vessels, heat exchangers, steam and water equipment, valves and other associated plant.

A sectional view of the reactor showing the general layout appears in Fig. 3. It has been designed to meet widely different requirements as simply and as inexpensively as possible and to provide high operating fluxes at low capital and running costs, together with operational stability and flexibility.

EXPERIMENTAL FACILITIES

The facilities available enable experimental work to be carried out in a wide range of subjects including the following: cross-section measurements, neutron diffraction, exponential experiments, food sterilisation by radiation, materials testing, irradiation damage, biological and medical research, shielding studies, control, instrumentation, and investigation of reactor characteristics. The reactor can also serve as a means of training personnel in reactor operation. The actual experimental facilities are: two thermal columns with external faces 4 ft. 6 in. square, a shelf to take canned materials, a hole 3 in. by 3 in. in cross-section passing vertically through the centre of the core, six 12-in. diameter holes ending as closely to the reflector face as possible, six 6-in. diameter holes ending as closely to the reflector face as possible, five 6-in. diameter holes passing right through the reactor parallel to a reflector face for use in " rabbit " experiments, and four 8-in. vertical holes to be used mainly for chemical experiments. Fig. 4 shows sections across the reactor in the three positions which the core may occupy and indicates some of the facilities.

The reflector area is divided into sections approximately 3 in. square, most of which are normally made available for irradiation studies by substituting a suitable canned experiment in the reflector section. The core is made removable to give access to the reactor tank for modifications to the experimental facilities. Each of the beam tubes may be removed from the outside of the shield, thus allowing some modification without any major shielding precautions.

The power level of the reactor is 1 MW for five to ten hours, or 100 kW continuously. At 100 kW the peak fluxes in the core are: for thermal neutrons approximately $1{\cdot}5 \times 10^{12}$ neutrons per square centimetre per second, for epi-thermal neutrons approximately 6×10^{12} neutrons per square centimetre per second, and for gamma radiation 10^7 röntgens per hour. The peak thermal flux in the reflector is about $1{\cdot}05 \times 10^{12}$ neutrons per square centimetre per second, and the maximum thermal flux available at the end of the experimental holes is 3×10^{11} neutrons per square centimetre per second. There is a proportional increase in flux at a power level of 1 MW.

THREE CORE POSITIONS

The core of the reactor is moderated and cooled by light water, while the reflector is arranged to permit the use of various alternative materials. In order to accommodate the large number of experimental tubes, the core is designed to occupy any one of three vertical positions, and the tubes and thermal columns are distributed among these three positions to take best advantage of the available space. The concrete shield and the water depth are such as to afford adequate shielding at all the working positions including the open top of the reactor, while the experimental tubes are provided with suitably designed plugs so that there is no excessive radiation when they are not in use. The outer face of the concrete shield includes a steel framework and separate steel plates to facilitate the mounting of experimental apparatus near the beam tubes.

The core is cooled by circulation of the water used as moderator. This water may be circulated through a water-water heat exchanger, and the secondary circuit of this is cooled by a mechanical-draught cooling tower or local water supply;

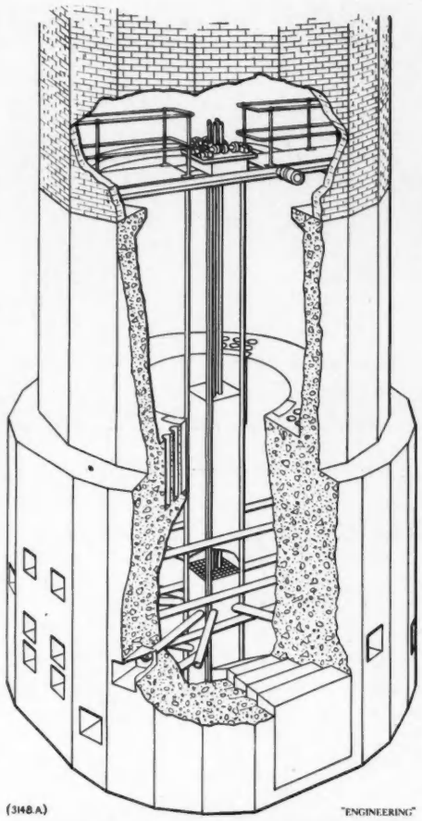


Fig. 3 Light-water moderated and cooled ("swimming pool") research reactor offered for sale by the Associated Electrical Industries and John Thompson industrial nuclear energy group.

alternatively, the primary water may be cooled in an air-blast cooler. In order to confine the hot-water path through the reactor, the core is surrounded by an aluminium flume which extends from the base of the tank to an upper position where the hot water is drawn off for re-circulation. At the same time, some of the bulk water is also extracted, cooled and re-circulated, to hold its temperature at a reasonable level. The inlet to the flume is so designed that in the event of failure of the forced cooling circuit, there will be an appreciable circulation of water by natural convection, thus safeguarding the core after shut-down. The primary water is fully de-mineralised by hydrogen ion exchange equipment, and a high degree of purity is maintained by continuous by-pass re-circulation through the demineralisation plant and by intermittent filtering. The induced activity in the water is thus reduced to a negligible amount.

The core and reflector assembly consists of small sections supported in a framework. The sections may be removed separately by means of a simple loading rod, which enables this operation to be completed at working depth in the water. Suitable mechanical interlocks are provided to prevent any error during loading and unloading. The separate elements can be stored in any of 48 storage holes which are situated within the bulk shield; the storage holes are adequately shielded to allow access to the inner tank when the core and its framework have been removed. The holes will also hold control rods and small irradiated samples prior to removal in a coffin.

SAFETY AND CONTROL

The core is protected by two safety rods and two control rods—one coarse and one fine. All the rods enter the core under gravity and are controlled from a position vertically over it above the water level. The coarse control rod is of sufficient capacity to shut down the reactor in an emergency, while the fine control rod and associated control system ensure stability of the flux-level during operation. Interlocks and safety circuits are incorporated so that in the event of maloperation or unusual circumstances the coarse control rod will drop. Failure of this rod to operate correctly is safeguarded by the two safety rods.

Four ion chambers are situated at the corners of the core and a fission chamber at the core centre. Adequate instruments are provided to start up and shut down the reactor and to observe flux levels, water activity, tolerance levels round the reactor and water temperatures during running. These instruments and controls could usefully be installed near the top of the reactor, but can, of course, be in any position most convenient for operation. The automatic control system for the fine control rod will maintain the flux level at full power to an accuracy within $\pm$ 1 per cent. during operation.

The A.E.I.-John Thompson group also includes Sunvic Controls Limited, 10 Essex-street, Strand, London, W.C.2, who are concerned with process control, and instrumentation, and W. S. Atkins and Partners, 158 Victoria-street, London, S.W.1, consulting civil engineers.

CALDER HALL

Another group of companies formed to undertake atomic power projects includes the English Electric Company, Limited, Marconi House, Strand, London, W.C.2, Babcock and Wilcox Limited, Farringdon-street, London, E.C.4, and Taylor Woodrow Limited, Ruislip-road, Southall, Middlesex. This group is specially interested in installations employing gas-cooled graphite-moderated reactors, and it is on this principle that Britain's first nuclear power station at Calder Hall will operate. Taylor Woodrow have been engaged in the building of this plant and Fig. 1 shows construction work on the site proceeding by floodlight. Number two reactor can be seen in the foreground with the turbine hall, while beyond are reactor number one and the first cooling tower. Details of the stands exhibited by this group at the Geneva fair will be published in a forthcoming issue.

To be continued

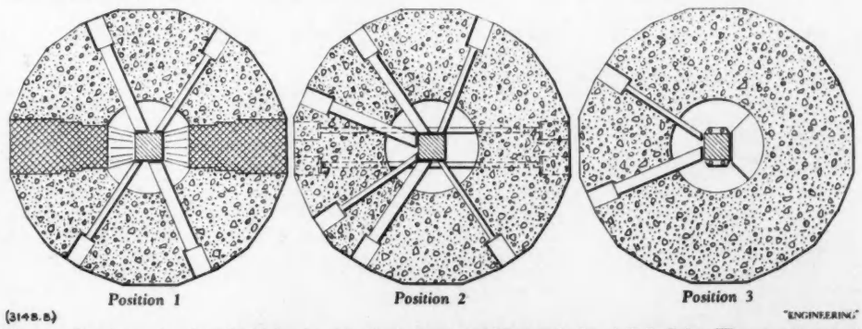


Fig. 4 Sections showing facilities in the three core positions of the A.E.I.-John Thompson group research reactor. These facilities permit studies in such subjects as cross-section measurement, exponential experiments, food sterilisation, materials testing, and medical research. The group also includes Sunvic Controls, Ltd., and W. S. Atkins and Partners, civil engineering consultants.

Fig. 1 The Gyron-Sperrin flying test-bed: de Havilland Engine Company, Limited.

THE AIRCRAFT INDUSTRY DISPLAY

(1) GAS TURBINE DEVELOPMENTS

Throughout this week the Society of British Aircraft Constructors have been holding their annual flying display and exhibition at Farnborough, Hampshire. It ends on Sunday. Last week we gave a list of the aircraft likely to be flown, and we suggested that the principal sources of interest this year were the new power plants, since it is in this field that the British industry holds an undisputed claim for leading place. On view for the first time at Farnborough are the de Havilland Gyron jet and the Rolls-Royce Conway by-pass engine; the Bristol Orpheus lightweight jet; and the Napier Oryx helicopter gas turbines.

GYRON : 15,000 LB. THRUST

Envisaged as a power plant for supersonic aircraft in combination with a booster rocket engine, the Gyron was designed in 1950 by the de Havilland Engine Company, Limited, Edgware, Middlesex, as a private venture, and ran for the first time in January, 1953. It was officially adopted by the Ministry of Supply in April, 1953. On July 7 this year it commenced its flight tests, one Gyron being installed in the lower port nacelle in place of one of the four Rolls-Royce Avon engines of a Short and Harland Sperrin SA4 research aircraft (Fig. 1). Later in the year a second Gyron will replace the Avon in the lower starboard nacelle.

On the eve of the display it was officially announced that the Gyron, which is illustrated in Fig. 2, had passed the Government type approval test at an initial thrust rating of 15,000 lb. without afterburning. The length of the engine is 154 in. and its overall diameter, without accessories, is 46·25 in. The weight has not been revealed, but it is known that the Gyron has a very high thrust-to-weight ratio. Reference to Fig. 1 shows that, although the overall diameter of the Gyron is only some 4 in., more than that of the Avon, the intake area is very much greater.

It may be of interest to recall that the chief engineer of the de Havilland Engine Company, Dr. Eric S. Moult, recently presented a paper before the fifth Anglo-American Aeronautical Conference on "Power Plants for Supersonic Aircraft," in which he concluded that the supersonic engine required only a moderate pressure ratio, but that it was of prime importance to match the intake to the breathing requirements of the engine, possibly by varying the intake area by means of an adjustable centre body. He concluded also that tremendous gain in ceiling, speed and manoeuvrability at altitude could be obtained by using rocket boost for short periods in conjunction with the turbojet.

The liquid-fuel Spectre rocket which the de Havilland Engine Company have developed as a booster for use with the Gyron is due to make its first flight shortly. To date no details have been released on this engine.

The existence of a smaller member of the Gyron family, the Gyron Junior, has also been revealed. This engine, being developed under a Ministry of Supply contract, has recently run for the first time. No details of its performance, dimensions, or construction are available.

CONWAY : 13,000 LB. THRUST

On the stand of Rolls-Royce Limited, Derby, is the Conway by-pass engine, recently type-tested at 13,000 lb. thrust, and stated by its manufacturers to have the lowest specific fuel consumption of any jet engine so far type tested. The Conway (Fig. 3) will power the four-engine Vickers-Armstrongs V.1000 military transport aircraft now under construction. As a result of its low fuel consumption, the Conway is arousing great interest among air liner constructors and operators, and it is known that Douglas Aircraft Company, Incorporated, California, have it under consideration as a potential power plant for export versions of the D.C.8 jet liner.

The principle of the by-pass engine, invented by Whittle, is illustrated in Fig. 4. In the words of the chief engineer of the Rolls-Royce aero engine division, "the early compressor stages are made oversize, the surplus air then by-passes the high pressure section of the engine and rejoins the main gas stream directly after the turbines. Energy is removed from the exhaust gases and is added to the by-pass air, thus a final jet of increased mass-flow but reduced velocity is produced." At speeds in the high subsonic range, this produces a higher overall efficiency than the pure jet; and, on account of the low velocity of the exhaust gases, the noise level is much lower than that of a pure jet engine. The duct of cool air which surrounds the hot part of the engine also simplifies engine compartment cooling and fire-protection problems.

The Conway has already been test-flown in a Conway-Ashton flying test bed, and this aircraft is also taking part in the display. The engine is installed in an accessible pod under the fuselage; an engine-loading trolley has been provided to facilitate fitting. The whole conversion of the airframe was carried out for the National Gas Turbine Establishment by the Napier Flight Development Establishment at Luton, the pod being offset by 12 in. to port of the aircraft centre line to provide clearance between the engine intake and the crew escape chute. To avoid any possibility of damage by vibration from the jet efflux, the pressure bulkhead in the aircraft has been moved forward of the pod jet pipe, and temperature-sensitive paints have been used on the underside of the fuselage to ensure that no significant temperature rise occurs at this position. Later, when afterburning tests are to be carried out, an acoustic and temperature shield will be provided.

THE LIGHTWEIGHT ORPHEUS

The lightweight Orpheus axial-flow turbojet, designed and constructed by the Bristol Aeroplane Company, Limited, Filton, Bristol, has a promising future. It has been selected as the power unit for all the NATO tactical-fighter prototypes—the Breguet Taon, the Dassault Mystère XXVI and the Fiat G.91, as well as for the Royal Air Force's own lightweight fighter, the Folland Gnat. The Orpheus is displayed in the static exhibition as well as in the air on the Gnat prototype and is illustrated in Fig. 5 opposite.

Over 2,200 hours test running have been completed since the first Gnat was run on December 17 last year—little more than a year after the Bristol company had decided to develop the

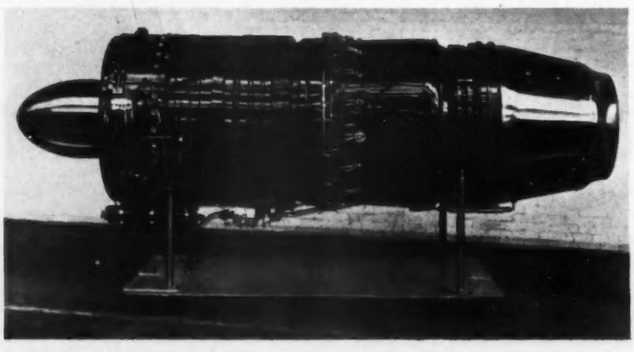


Fig. 2 The Gyron turbojet: de Havilland Engine Company, Limited.

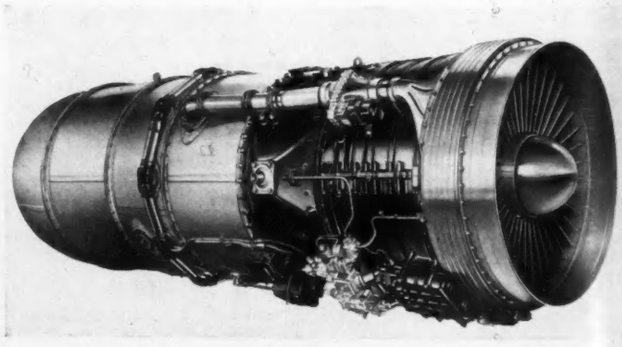


Fig. 3 The Conway by-pass jet: Rolls-Royce, Limited.

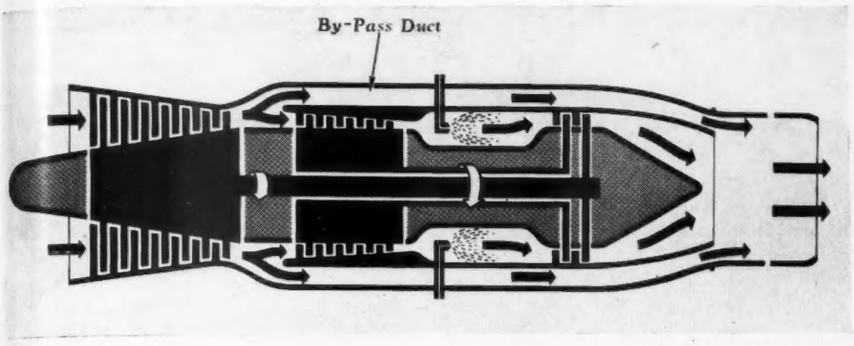


Fig. 4 Principle of the by-pass jet. Surplus air from oversize compressors by-passes the high-pressure section of the engine, takes energy from the exhaust gases and is used to produce a final jet of increased mass-flow but reduced velocity.

engine. In May this year the Orpheus was successfully type tested at a static thrust of 3,285 lb., at which the corresponding thrust-to-weight ratio is 4·4 lb.-thrust per pound weight, the highest figure yet attained by an engine that has passed the 150-hour type test. Other versions of the Orpheus have already developed considerably higher thrusts. The diameter of the Orpheus is 32 in. and its overall length is 97·6 in.

HELICOPTER GAS TURBINES

Gas turbines for helicopter drives are becoming a speciality of D. Napier and Son, Limited, Acton, London, W.3, who have on view at Farnborough for the first time the Oryx, and the Rotodyne Eland. They are also developing a 1,260-h.p. shaft turbine for helicopters, the Gazelle, about which no information has been released to date.

The Oryx gas generator, described in detail in the August 5 issue of ENGINEERING, develops 750 g.h.p. at sea level and is to be installed shortly in the Hunting-Percival P.74 reaction-drive helicopter; the exhaust gases from the Oryx are ducted to the rotor head and thence through the rotor blades to tangential tip jets. It seems possible that this arrangement should go a long way towards solving the problem of avoiding ice formation on rotor blades.

The Rotodyne Eland N.E1.3, which is to power the Fairey Rotodyne helicopter, has also been described in ENGINEERING, on page 864 of the December 31, 1954, issue. Developing 3,000 e.h.p., it is a standard Eland gas turbine with an auxiliary compressor at the end of the turbine, connected to the turbine shaft through a hydraulic clutch, so that power can either be taken through the propeller for forward flight or, for vertical flight, through the auxiliary compressor, which provides the compressed air supply for fuel-burning jets at the rotor blade tips.

Helicopter power units are also displayed by Blackburn and General Aircraft Limited, Brough, East Yorkshire, who manufacture the French Turboméca small gas turbines under licence. The Palouste 500 turbo-compressor, which has an output of 2·725 lb. per second of free air at 56 lb. per square inch absolute at 15 deg. C., is the compressed-air source for the Fairey ultra-light helicopter, which is of the fuel-burning tip-jet type.

The Coupled Turmo engine shown by Blackburn has been developed as a power plant for shaft-driven helicopters. It comprises two Turmo free-turbine units driving through common gearboxes while retaining the ability to operate independently. Two versions are available, the Coupled Turmo 500 and the Coupled Turmo 600, the latter being on view at Farnborough; common to both are the overall dimensions—length 54 in., width 42 in., height 18 in.—and the net dry weight, 598 lb. The Coupled Turmo 600 has a higher air mass flow, 14·38 lb. per second, than the Coupled Turmo 500, 9·4 lb. per second, and a slightly lower pressure ratio, 4·12 to 1 as against 4·19 to 1. The maximum powers are 900 e.h.p. for the 600 series engine and 670 e.h.p. for the 500 series engine; the corresponding specific fuel consumptions being respectively 1·04 and 0·92 lb. per h.p. per hour.

Blackburn and General Aircraft, Limited, are also showing other Turboméca-type engines, including the basic jet engine, the 390-lb. thrust Palas 600 centrifugal jet; the single Turmo and the coupled version (Fig. 6), itself a Palas 600 driving a free power turbine; the 883-lb. thrust Marboré jet engine; and the Marcadau 600 propeller turbine, which is in fact an Artouste shaft turbine driving a propeller. The Marcadau, which has an air mass flow of 7·19 lb. per sec. and a pressure ratio of 4·12 to 1, develops a maximum shaft power of 475 h.p., plus 64 lb. jet thrust, with a corresponding specific fuel consumption of 0·95 lb. per lb. thrust per hour. It has a net dry weight of 303 lb., an overall length of 53 in., width 18 in. and height 19 in.

ELAND ELIZABETHAN

The orthodox propeller turbine Eland N.El.1 is being exhibited in the static display, where it is shown sectioned and fitted with the Napier Spraymat de-icing system on the intake and spinner. In the flying display is an Elizabethan air liner, the Golden Hind, of British European Airways, which has been converted to 3,000-h.p. Elands in place of the standard 2,600-h.p. Centaurus piston engine. The Golden Hind is to be handed over to B.E.A. after the display for flight evaluation and is expected to go into service as a freighter in about a year's time. The performance of the Eland Elizabethan is expected to be appreciably better than the standard version, since in addition to providing more power the total Eland installation is appreciably lighter than the Centaurus installation. Later developments of the Eland engine envisage take-off powers up to 4,200 e.h.p.

SAPPHIRE, MAMBAS AND OLYMPUS

Among other engines on view at Farnborough, the Sapphire ASSa7 axial-flow jet designed and constructed by Armstrong Siddeley Motors, Limited, Coventry, has been type-tested at 10,500 lb. and is in production. The 2,850-e.h.p. Armstrong Siddeley Double Mamba ASMD1 has gone into service in quantity in the Fairey Gannet, and the Double Mamba ASMD3 has been type-tested at 3,035 e.h.p. The Armstrong Siddeley long-life Viper 5, with a static life of 1,640 lb., is going into service in the Hunting-Percival Jet Provost, and a higher-powered version, the Viper 8, has run at 1,750 lb. static thrust.

Again appearing in the flying display is the Olympus Canberra flying testbed for the Olympus engine, which last week set up a new world height record of 65,876 ft. For this flight, a new version of the Olympus engine, the BO1.11, was fitted; the performance of this engine has not been released. Early this year the Olympus 101 was officially approved for service at a static thrust rating of 11,000 lb. without afterburning. In America, the Olympus is the subject of a licence agreement between Bristol and the Curtiss-Wright Corporation, the American version being known as the J.67.

Subsequent articles will deal with other aspects of the display.

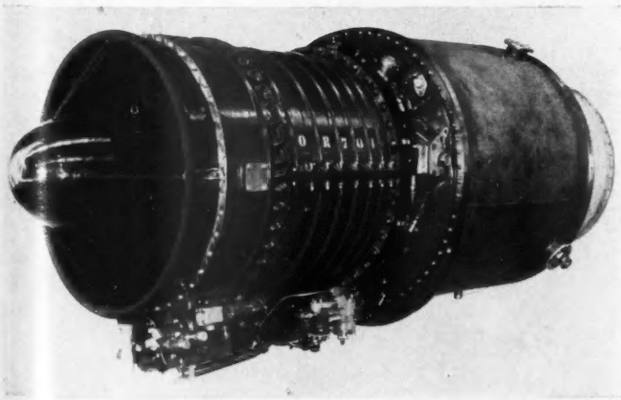


Fig. 5 The lightweight Orpheus turbo-jet: Bristol Aeroplane Company Limited.

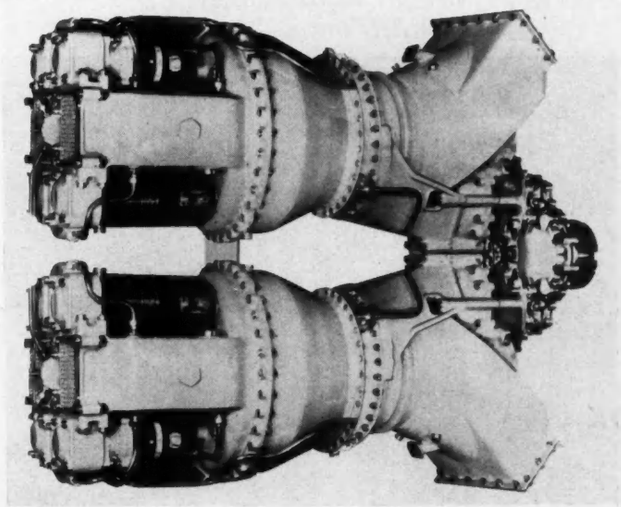
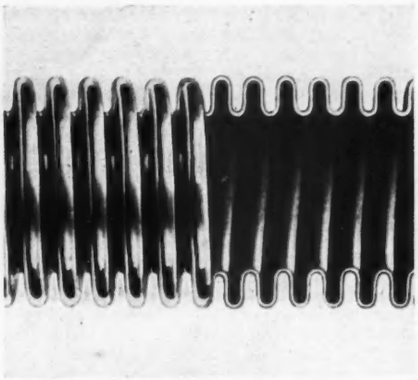


Fig. 6 The Coupled Turmo shaft turbine: Blackburn and General Aircraft Limited.



Flexible seamless stainless steel tubing is being produced in seven sizes with bores from $\frac{1}{16}$ in. to $\frac{1}{4}$ in. It is designed particularly for use in the aircraft industry.

FLEXIBLE SEAMLESS STAINLESS STEEL TUBES

Stainless-steel tubes which are both flexible and seamless have been produced after considerable development work by Accles and Pollock, Limited, Oldbury, Birmingham. This type of tube is of particular interest to the aircraft industry, as the Weekly Survey note " Flexible stainless-steel tubes " on page 332, remarks. To produce the tubes economically as soon as possible a limited range of bores and gauges of tube has been established. The first range covers seven sizes with bores from $\frac{1}{16}$ to $\frac{1}{4}$ in., outside diameters from 0·32 in. to 1 in. and wall thickness from 0·006 to 0·014 in.

The flexible tube is made by producing helical convolutions in thin-walled stainless steel tube, the form of which is shown in the accompanying illustration. The plain tube for subsequent manufacture of flexible hose can be made from any of the popular types of austenitic stainless steel, and after convoluting the material is in the slightly cold-worked condition. During the convoluting operation the wall thickness is not reduced and the finished length is a little less than half that of the original plain tubing, which means that lengths of convoluted tubing are limited to about half the maximum lengths for cold drawn seamless tubes.

★ ★ ★

The Institution of Mechanical Engineers have published a brief subject and author index of papers in the *Proceedings* for the period 1937-54. Issues of the index previous to the 1937-51 edition covered the papers back to 1847, and should be kept for early records.

MAST ERECTION FOR ELECTRIC RAILWAYS

WAGON-MOUNTED EQUIPMENT SAVES TIME AND REDUCES TRACK OCCUPATION

Good progress is being made with the conversion to electric traction of the main line between Shenfield and Chelmsford (9½ miles) and the branch from Shenfield to Southend-on-Sea (21¼ miles) in the Eastern Region of British Railways. These works form an extension of the electrified lines between Liverpool Street and Shenfield (20¼ miles) which has already been described in ENGINEERING,* and will be of course operated on the 1,500 volt direct-current system, the current being supplied from an overhead line. Power will be obtained from the Central Electricity Authority's three-phase network and will be converted to direct-current in new substations at Hylands, near Chelmsford, on the main line and at Ramsden Bellhouse, Rayleigh and Prittlewell on the branch. The stations will be equipped with mercury arc rectifiers and will be remotely controlled from the existing control station at Chadwell Heath. There will also be three track sectioning cabins between the substations on the branch and one at Ingatestone on the main line.

In connection with this electrification a good deal of associated civil engineering work is being carried out. This includes improvements to the drainage and earth works and the insertion of sand blanketing resting on waterproofing material at places where water pockets have formed below the track. This has involved the removal of masses of saturated clay and the replacement of old by new ballast. The platforms at a number of stations have been raised and in some cases lengthened and, as in former schemes, it has been necessary to remove the arches of several brick bridges and to replace them by steel girders to provide sufficient room for the installation of the overhead traction equipment.

OVERHEAD LINE CONSTRUCTION

The most interesting part of the conversion work, however, is in the use of mechanical equipment to speed up the work of installing the foundations and erecting the masts for carrying the overhead conductors through which current is supplied to the trains. This development has considerably accelerated progress and has had the further effect of reducing the time the running line is occupied, a point of considerable importance where the traffic is heavy.

* Vol. 168, page 325 (1949)

The equipment, which has been developed by the contractors, British Insulated Callender's Construction Company, Limited, 21 Bloomsbury-street, London, W.C.1, in co-operation with Messrs. Wharton Engineers (Elstree), Limited, consists of an earth boring unit, an erection unit and a concreting unit, which together with a Diesel-electric set for supplying some of the power are mounted on individual wagons and formed into a train, as shown in Fig. 1. This enables all the necessary operations to be performed in sequence during one visit to the track.

The earth boring unit is illustrated in Fig. 2. It consists of a boring head which is driven by a Diesel engine and is mounted so that it can travel the length of its own track, rotate about its axis, traverse in an across-track direction and be raised, lowered and adjusted to the vertical for any cant of the track. The auger carried by the unit can thus be brought to the correct position over the site of the hole and the holes themselves bored up to a distance of 13 ft. 6 in. from the centre line of the track. The holes measure from 2 ft. to 3 ft. 6 in. in diameter and their maximum depth is 12 ft. The spoil is ejected from the auger head by spinning and can then be removed by hand.

MAST ERECTION

On completion of the boring operation steel ground frames are temporarily placed over the holes and the erection unit is then brought into position. This unit, as will be clear from Fig. 3, consists of a self-propelled steam crane which lifts the galvanised channel section masts into the excavations where they are held in the ground frames at their correct position and height. The crane is then hauled away and its place taken by the concreting unit, which is illustrated in Fig. 4. This unit, which is also mounted on a railway wagon, consists of two electrically-driven concrete mixers. Each of these mixers embodies a weigh batcher and between them is an electro-hydraulically operated placer. A telescopic jib enables the concrete, which is taken from each mixer in turn, to be placed in the hole. A 1 : 2 : 4 mix has been used, and after pouring, the concrete is vibrated pneumatically to assist the removal of moisture. (In the illustration the mast is not in position in order to show the equipment more clearly.) Fig. 5 shows the position of the work at the end of this operation

Fig. 1 Construction train for the erection of masts for overhead electrical equipment in the Eastern Region, British Railways.

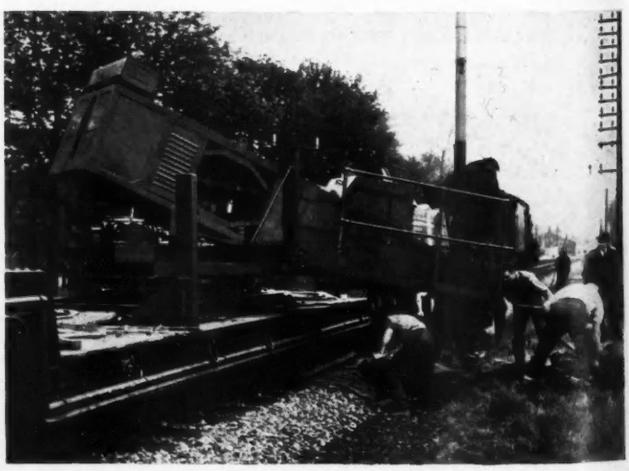


Fig. 2 Earth boring unit, showing the auger operating at normal distance from the rail.

Fig. 3 A mast being planted into a previously bored hole.

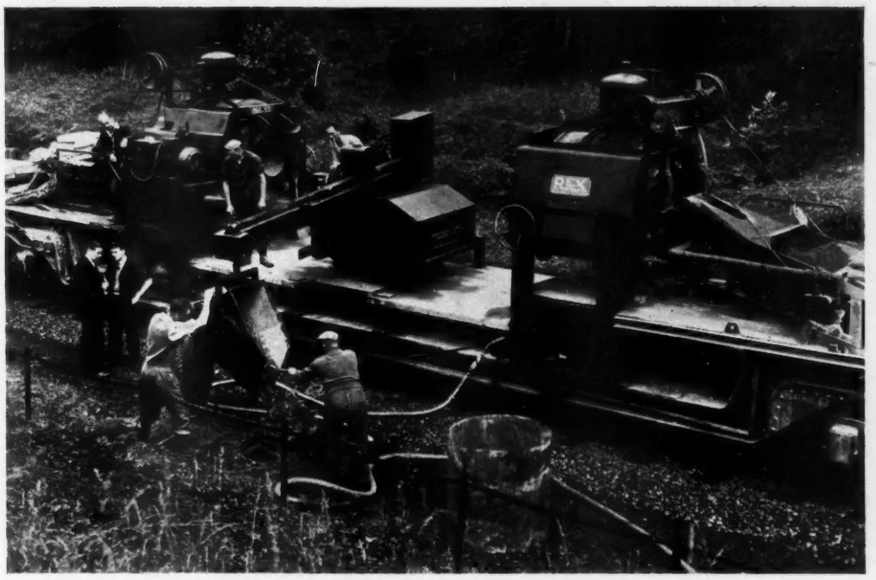


Fig. 4 Concrete being poured round steel core former. (The mast is not shown in position).

with the concreting completed. It also shows the temporary ground frame mentioned above and the cylindrical former which is used to shape the top of the foundation and keep any loose earth out of the hole. After 48 hours the concrete is sufficiently set to enable the frame to be removed.

Power for operating the concreting unit is obtained from a Diesel-electric set on another wagon which also carries pumps for delivering water to the mixers, and a compressor for operating the vibrators and other tools.

This construction unit enables all the foundations to be completed, all the masts on one side of one mile of track being erected in from four to five hours occupation. The masts on the other side are then erected in the same way, the only modification being that care has to be taken that they are exactly opposite those that have already been set up. At a later stage booms will be placed across the uprights to form a portal structure such is already in use on the Liverpool Street-Shenfield section. As before too, the overhead equipment will be of the compound type to ensure sparkless collection and will consist of main and auxiliary catenaries, the actual cadmium-copper contact wire being suspended from the latter by loop droppers. All this equipment will be supported from the underside of the booms by "Diabolo" type insulators so that the normal height of the contact wire above the track will be 16 ft. Arrangements will be provided to offset the contact wire at each structure to even the wear on the pantographs.

Fig. 5 Concreting completed. The mast is shown in position in the ground frame which is removed after 48 hours.

NOTICES OF MEETINGS

Association of Supervising Electrical Engineers

LONDON
Discussion on "Modern Practice in Television." Central London Branch. St. Ermin's Hotel, Caxton-street, S.W.1. Mon., Sept. 12, 7 p.m.
"Industrial X-Rays," by F. L. Veale. South East London Branch. Guild House, 32 Worple-road, Wimbledon, S.W.18. Wed., Sept. 14, 8.15 p.m.

BIRMINGHAM
"Relays and Automatic Control in Industry," by Dr. W. L. Stern. Birmingham Branch. Birmingham Chamber of Commerce, 95 New-street, Birmingham. Wed., Sept. 14, 7.15 p.m.

OXFORD
"Electric Heating, Heat Pumps and Hot Water from the Refrigerator," by A. W. Bates. Oxford Branch. The Y.M.C.A., 10 George-street, Oxford. Sat., Sept. 17, 6.30 p.m.

WATFORD
"Electricity in the Aircraft Industry," by K. Wade. Watford Branch. Clarendon Hotel, Station-road, Watford, Herts. Thurs., Sept. 15, 8.15 p.m.

YORK
"Miniature Circuit-Breakers," by F. Grant. York Branch. Shambles Café, York. Wed., Sept. 14, 7.15 p.m.

Building Centre

LONDON
Film, "Desert Bounty" (Kuwait Power Station and Distillation Plant). Wed., Sept. 14, 12.45 p.m.

Illuminating Engineering Society

BATH
"Interior Decoration and Its Effect upon Illumination," by J. D. Layton. Bath and Bristol Centre. Offices of the South Western Electricity Board, Old Bridge-street, Bath. Fri., Sept. 23, 7 p.m.

BIRMINGHAM
Chairman's Address, by G. R. Hanson. Birmingham Centre. Regent House, St. Phillip's-place, Colmore-row, Birmingham. Fri., Sept. 23, 6 p.m.

LEEDS
Trotter-Paterson Memorial Lecture on "The Brightness of the Stars," by Sir Harold Spencer Jones. Leeds Centre. Chemistry Lecture Theatre, The University, Leeds. Mon., Sept. 26, 7 p.m.

LEICESTER
"Interesting Lighting Jobs." Various short papers. Leicester Centre. Offices of the East Midlands Electricity Board, Charles-street, Leicester. Mon., Sept. 26, 6 p.m.

Incorporated Plant Engineers

BLACKBURN
"Corrosion: Prevention and Control," by Dr. G. Butler. Blackburn Branch. Golden Lion Hotel, Blackburn. Thurs., Sept. 15, 7.30 p.m.

BRISTOL
Discussion on "Coal and Oil." Western Branch. Grand Hotel, Bristol. Wed., Sept. 21, 7.15 p.m.

DUNDEE
Discussion on "The Use of Breathing and Resuscitating Apparatus." Dundee Branch. Mather's Hotel, Dundee. Mon., Sept. 12, 7.30 p.m.

MANCHESTER
Open Meeting. Manchester Branch. Engineers' Club, Albert-square, Manchester. Tues., Sept. 13, 7.15 p.m.

ROCHESTER
Discussion on "Building Construction for Industry." Kent Branch. Bull Hotel, Rochester. Wed., Sept. 21, 7 p.m.

Institute of Petroleum

LONDON
"Modern Crude-Oil Loading Techniques at Mina-al-Ahmadi, Kuwait," by J. M. Dougary. Wed., Sept. 14, 5.30 p.m.

Institute of Road Transport Engineers

DURHAM
"Gas Turbine Development for Road Transport," by P. A. Phillips. North Eastern Centre. Three Tuns Hotel, Durham City. Tues., Sept. 27, 7 p.m.

LEEDS
"Multi-Purpose Lubricating Oils," by P. H. G. Crick. Yorkshire Centre. Great Northern Hotel, Welling-street, Leeds, 1. Thurs., Sept. 15, 7.30 p.m.

LIVERPOOL
"Gregoire Suspension," by J. Clifford. West Regional Centre. Adelphi Hotel, Lime-street, Liverpool. Tues., Sept. 13, 7.30 p.m.

MANCHESTER
"Selection and Maintenance of Light Commercial Vehicles," by C. D. H. Stead. East Regional Centre. Houldsworth Hall, 90 Deansgate, Manchester. Mon., Sept. 12, 7.30 p.m.

Institution of Locomotive Engineers

LONDON
Presidential Address, by K. J. Cook. Institution of Mechanical Engineers, 1 Birdcage-walk, St. James's Park, S.W.1. Wed., Sept. 21, 5.30 p.m.

Institution of Production Engineers

LONDON
"Industrial Gases with Particular Reference to Oxygen and Acetylene," by F. D. Hucklesby. London Graduate Section. Wed., Sept. 21, 7.15 p.m.

DUNDEE
"The Practical Application of Production Engineering Research," by Dr. D. F. Galloway. Dundee Section. New Imperial Hotel, 15 Tally-street, Dundee. Wed., Sept. 14, 7.30 p.m.

MANCHESTER
"The Gas-Turbine Locomotive," by P. E. Stock. Manchester Graduate Section. College of Technology, Sackville-street, Manchester. Mon., Sept. 12, 7.15 p.m.
"Lubrication," by Dr. H. E. Priston. Manchester Section. College of Technology, Sackville-street, Manchester. Mon., Sept. 19, 7.15 p.m.

NEWCASTLE-UPON-TYNE
Chairman's Address, by F. Baker. North Eastern Section. Neville Hall, Westgate-road, Newcastle-upon-Tyne. Mon., Sept. 19, 7 p.m.

SHEFFIELD
Practical Lecture on "Screw Thread Gauging." Sheffield Graduate Section. Inspection Establishment, Janson-street, Sheffield. Mon., Sept. 19, 6.30 p.m.

The address and telephone number of the headquarters of each institution are given below. Meetings in the headquarters town are held there unless otherwise stated. Particulars for this column should reach the Editor not later than Monday morning in the week preceding the date of the meeting.

Association of Supervising Electrical Engineers, 23 Bloomsbury-square, London, W.C.1. (LANgham 5927.)
Building Centre, 26 Store-street, London, W.C.1. (MUSeum 5400.)
Illuminating Engineering Society, 32 Victoria-street, London, S.W.1. (ABBey 5215.)
Incorporated Plant Engineers, 48 Drury-lane, Solihull, Birmingham. (Solihull 3021.)
Institute of Petroleum, Manson House, 26 Portland-place, London, W.1. (LANgham 2250.)
Institute of Road Transport Engineers, 69 Victoria-street, London, S.W.1. (ABBey 6248.)
Institution of Locomotive Engineers, 28 Victoria-street, London, S.W.1. (ABBey 6672.)
Institution of Production Engineers, 10 Chesterfield-street, London, W.1. (GROsvenor 5254.)

THE HUMAN ELEMENT

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An industry's wages based on scientific methods; more apprentices, more training; cost-of-living index abandoned as a wage corrector; trouble in Germany; and fatigue (human, not metallic).

The Dundee Experiment

How a new wages structure was worked out after the war for a whole industry was the subject of a paper by Mr. I. F. Gibson, "The Rationalisation of Wages—A Case Study," given at this year's British Association meeting. Briefly, the background was this. The Dundee jute industry was faced with the need to undertake a large-scale modernisation programme after the war. In pre-war years there had been chronic depression and a deterioration of labour-management relations: a Trade Board pinned minimum wages from 1920 onwards but this was a poor palliative. It was clear that the modernisation plan could not go forward without big changes in the wage structure.

In 1950, discussions began between the representatives of the employers and those of the three unions involved, with a firm of industrial consultants to give expert advice to both parties. All jobs in the industry were evaluated on a points basis, which were then converted into money terms and introduced gradually into each works with due regard to work measurement, redeployment, work loadings and so on. Traditional differentials between male and female wage rates were preserved by a special weighting in the points system. The agreement between the employers and the unions was finally reached in November, 1952. Most operatives affected earned more under the new scheme than under the old one but special provision was made for older workers who could not work to the new work load ratings and also for juveniles. The process of substituting the new structure of wages for the old is still going on. So far, evidence shows that workers have received larger pay packets under the new system, notably those on time rates. Employers have benefited from lower labour turnover, higher machine utilisation, a simpler negotiating system and greater interest on the part of the workers in better methods of management.

Such a wages system is, of course, open to the criticism that it works smoothly and simply only as long as basic wage differentials are unchanged, which in turn means that these differentials will alter as soon as job evaluations change relative to one another. The industry has indeed taken on the same sort of perpetual work study as an individual company must have, say, when it pays its workers a bonus based on proper job evaluation. The sheer size of such an undertaking can well be imagined for an industry as complex as engineering. Nevertheless, here is an interesting example of a bold bid by an industry to establish wage payments on scientific methods.

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Training for Skilled Trades

Some radical thinking on manpower and training young people was called for by Mr. Alec Rodger in his Presidential Address to the Psychology Section of the British Association last week. The nation, he said, faced the prospect that automation may seriously affect our ideas about training industrial manpower. Furthermore, in seven years time the number of young people of 15 leaving school will have increased from 625,000 to 927,000. "Is industry ready to take advantage of the fact that for every two boys of high capacity leaving school to-day there will be three by 1962?" Mr. Rodger, who is Reader in Psychology at Birkbeck College, London, also had a good deal to say about the wastage of time and manpower in existing apprenticeship arrangements. Much had been done in some industries to put matters right but there were still too many instances of agreements reached at national level being badly implemented locally.

The problem behind all this is a challenging one. Automation, no matter at what speed it may develop in British industry, will take the less dramatic form (in most people's eyes) of a greater capital investment in machines and equipment per worker. No matter in what way automation affects the proportion of skilled to unskilled workers employed in industry, there will certainly have to be a higher proportion of brain power, of trained intellect, per unit of output. That trained intellect will have to be made available to a large extent in the next decade or so by those who are now in the advanced stage of industrial training. It will take the concerted effort of both management and trade union representatives to will the means by which these men get adequate experience. Are existing training arrangements for the young in industry adequate to meet the challenge? The time to check on them is now, in the 1950's.

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Peace in Printing?

A settlement was reached last week between the Newspaper Proprietors' Association and half the unions involved about pay increases which have been in dispute for nearly 12 months and which caused the newspaper strike earlier this year. Increases in pay amounting to between 12*s.* and 19*s.* a week and back-dated to June 15 have been agreed, but these are rather less than half the demand made at the time of the strike. The unions which staged the strike in the spring, the E.T.U. and the A.E.U., have both accepted the terms of the arrangement and so have a number of the craft unions. Some unions will give their views in the next few days (these are expected to be favourable) and there are wage negotiations pending this autumn with representatives of provincial operatives, but it is generally thought that the present series of negotiations will bring peace for some time. Something like 350,000 workers are affected by the change.

Two matters of importance, apart from the actual terms of the settlement, emerge from this dispute. Six unions joined in the negotiations with the employers. and it will be recalled that both the E.T.U. and the A.E.U. made much of the fact at the time of the strike that hitherto they had been excluded from joint negotiations in this industry. It remains to be seen if this latest joint endeavour sets a precedent for the future, or whether formal joint machinery between the unions will have to be established. If the latter is the case, it is to be hoped that it will be done by other means than inconvenience to the public and cost to the industry, as happened in the spring.

The second matter of importance is that the sliding scale system has been dropped by the printing industry. Operatives have complained that the official index of the cost of living is too insensitive to true changes in the cost of living. This means that instead of accepting gradual changes in wage rates in response to retail price changes as recorded in the official index, they will rely on periodic wage negotiations. All the more reason, then, to improve inter-union consultation if the machinery of wage negotiation is to be used more frequently.

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Cooler Heads in Germany

Recent signs of increased pressure by German workers for higher wages as they become increasingly conscious of their bargaining power under full employment appeared in a more acute form towards the end of last month. A wave of unofficial strikes broke out. In Kassel 11,000 workers walked out of a locomotive works and sections of two shipbuilding yards at Hamburg were brought to a standstill. These were the usual signs of local opinion getting out of step with the top-level union representatives, who are now engaged in a complicated manœuvre with Professor Erhard, Minister of Economic Affairs. He is meeting the unions along with certain other members of Dr. Adenauer's Cabinet early this month. The unofficial strikers have now mostly gone back, though political agitators with East German connections did their best to keep them out.

If the unions can help it, pressure will be built up not by a rash of unofficial strikes but by continued demands from industrial areas throughout Germany by union officials for higher wages for their members. The peak is expected to be reached when the demands from the Ruhr steel workers are tabled early this month. Up to this point the whole affair is not of very great interest outside Germany. The attitude of the German Government, however, has added a wider significance to the situation. Some time ago, Dr. Erhard let it be known that he hoped to offset the dangers of a possible spiral of wages and prices developing by reducing prices rather than capitulating to demands for higher wages. It is clear that he does not expect the unions to forego completely their demands for higher wages but he hopes to contain their demands by active measures to get prices down. His main hope in this direction is more imports for the domestic market, which will thus mop up purchasing power, and he hopes to bring this about by reducing certain duties and permitting private importation by mail order. He would also like penalties against profiteering. It will certainly be an achievement if he can bargain successfully with the unions and liberalise trade at the same time. The two objectives are not inconsistent.

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What is Fatigue?

We all find work wearisome at times. What is the connection, if any, between this very common complaint and that rather technical word beloved of time and motion study men called "fatigue"? Much spasmodic research has been done on this subject to find out what fatigue really is and how it can be measured. Of late, systematic work has been carried out by the Royal Air Force, who are vitally interested in the problem from the point of view of air-crews, and a paper called "Recent Experimental work in the Study of Fatigue" was given to the British Association last week, by Mr. D. C. Fraser, who is senior psychologist at the aviation medicine department of the R.A.E.

The experts have arrived at a definition of fatigue and a method of measurement but they are still less confident than the layman about the meaning of the word and how to assess the phenomenon. To them it is "a disorganisation of receptor-effector co-ordination" and is closely related to an individual's capacity to time his reactions; time, that is to say, in the sense of co-ordinate. It is becoming apparent that there are different kinds of fatigue and individuals react to them differently. It is not the same thing as weariness or boredom and it appears to affect high-grade performance long before it is seen in physiological exhaustion of the worker.

In addition to systematic work on special problems and conditions a number of tentative conclusions of general interest have emerged. For example, certain opinions can be expressed about that old industrial problem, namely, fatigue and the time of day. From subjects tested it would appear that there are two kinds of people, one group shows greater fatigue in the morning, the other at night. The afternoon is neutral. There are a significant number of cases to show that alcohol is not a stimulant but increases fatigue. It looks as though the days in which we can plead a scientific justification for the afternoon tea break or a glass of beer are numbered.